The Art of Intramedullary Nailing for Femoral Fracture

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Preface

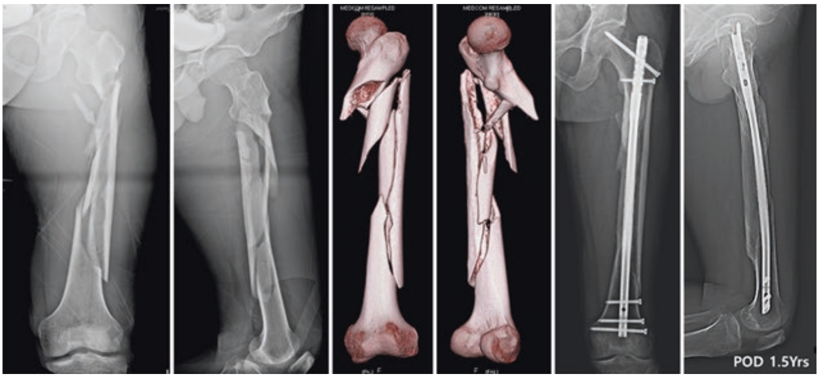
I remember learning intramedullary (IM) nailing by myself 35 years ago. There was no senior doctor familiar with the closed IM nailing technique in our department, so I encountered many troubles during initial practice. Creeping learning curves for finding appropriate entry points, closed reduction techniques, and freehand interlocking screw insertion disappointed me from time to time. However, trial and error in every step of IM nailing carved me to become an expert in this technique.

Moreover, it also let me understand the reasons for troubles and find solutions. Nowadays, many surgeons are experts in IM nailing techniques because it has been a treatment of choice for femoral shaft fracture for several decades. In addition, the number of surgeons who prefer cephalomedullary nailing for trochanteric fracture surpasses those who advocate sliding hip screw. IM nailing for the femoral fracture is quite popular these days. The implants and instruments have been developed for decades for better procedures and results.

In this book, I intended to illustrate the confusing points during IM nailing step by step, making them more straightforward for learning the IM nailing procedure. This book is written based on my career of 35 years in trauma. I stuck to my cases to show the readers many intraoperative images (to show them how I overcame the troubles during the surgery) and the consequences of the treatment. I hope the figures in this book will be imprinted in the brains of young surgeons so that they can recall them as a guide for successful IM nailing. I made this book as simple as an atlas with many figures and as detailed as a textbook. All the figures precisely describe the situations that I encountered during the procedures.

Most of all, I would like to express my sincere appreciation to Prof. Chang-uk Oh and Dr. Dong-hoon Lee for their contributions to Chapter 5 “Retrograde femoral nailing” and Chapter 12 “Limb lengthening using intramedullary lengthening nail,” respectively. As I preferred antegrade femoral nailing to retrograde one, I might have performed antegrade femoral nailing in some cases which could have been treated more easily with retrograde femoral nailing. Another specialty in IM nailing is deformity correction and lengthening of the deformed femur using a medullary saw and expandable nail. The two professors filled the gaps in my expertise and helped me make this book as complete as possible. I thank them once again. I also thank Mijeong Lee for the hard work she put into the proofreading of the manuscript.

I hope this book will guide the readers in performing challenging femoral nailing, as shown below. First, let's make a preoperative plan and imagine the procedures. Restoration of anatomic alignment with minimal handling of soft tissue and effective use of an implant led to successful results in this case.



Correct sequences of IM nailing in this case are:

1. Correct external rotation and flexion deformity of the proximal fragment.
2. Make an appropriate entry point under fluoroscopic guidance.
3. Ream the trochanteric area with a tapered reamer.
4. Perform closed reduction using IM reduction devices.
5. Confirm the correct placement of a ball-tip guidewire.
6. Ream the medullary canal.
7. Insert the appropriate nail (length and diameter).
8. The use of a Poller screw is recommended to correct the axial malalignment.
9. Interlock the proximal fragment through the targeting guide (at least one femoral neck and head screw).
10. Abduct the injured limb and verify the rotational status of the femur.
11. Interlock the distal fragment.

Each step will be described in detail in the following chapters.

Sungnam, Republic of Korea Kyu Hyun Yang
April 30, 2022

Contents

About the Author

Kyu Hyun Yang, M.D., Ph.D. dedicated himself to developing orthopedic trauma for 32 years of his carrier in the department of orthopedic surgery, Yonsei University College of Medicine, Seoul, Korea. He became an orthopedic surgeon in 1985 and confined his work to orthopedic trauma during his whole carrier. He learned traumatology at the Raymond Poincare Hospital, Paris V University (1991) and Mayo Clinic (Rochester, Minnesota, 1992). After foreign services, he returned to Yonsei University. He served as the President of the Korean Fracture Society and the Korean Society of Bone and Mineral Research. He is also an active international member of the Orthopaedic Trauma Association and the American Society of Bone and Mineral Research. He has been a consultant for Zimmer-Biomet for 20 years. He was one of the developers of the ZNN nail series. He believes the ZNN femoral nail is the best product in that series. So, the main field of his research and articles are the technique of intramedullary nailing of the femur: After retirement from the Yonsei University in 2021, he started a new carrier at the Armed Forces Capital Hospital to treat injured soldiers.

Abbreviations

AD II	Autosomal dominant II osteopetrosis
AFF	Atypical femoral fracture
AP	Anteroposterior
APCT	Abdomino-pelvis CT
BP	Bisphosphonate
CT	Computed tomography
DXA (DEXA)	Dual-energy X-ray absorptiometry
EN	Exchange nailing
GT	Greater trochanter
IM	Intramedullary
LT	Lesser trochanter
MIPO	Minimally invasive plate osteosynthesis
MRI	Magnetic resonance imaging
OPD	Outpatient department
PA	Plate augmentation
PTH	Parathyroid hormone
THR	Total hip replacement
TKA	Total knee arthroplasty
ZNN	Zimmer Natural Nail

1 Brief History of Evolution of Femoral Nail

During World War II, Gerhard Küntscher introduced a successful intramedullary (IM) nailing technique for femoral shaft fracture. He published his early work in "Technik der Marknagelung" (Intramedullary Nailing Technique) in 1945. He clearly stated that the IM nailing operation's principle consists of using a stab wound incision some distance from the fracture and the insertion of a steel nail into the marrow cavity of the broken femur [1–5]. He already recognized the benefits of a minimally invasive technique, which respects soft tissue around the fracture site to decrease the incidence of delayed healing and postoperative infection.

1.1 First-Generation Nail: Open Section Rod Type Nail

The Küntscher nail was initially developed as a V-shaped nail and later upgraded to a cloverleaf nail. The Küntscher nail was usually inserted into the medullary canal after the medullary reaming to insert a large diameter nail which provides more nail strength and greater contact areas with the femoral shaft. Surgeons believed that expansion of the squeezed nail generates tremendous contact pressure and friction between the nail and the isthmus of the femur. Drawbacks of this system were the requirement of medullary cortical reaming, inability to prevent the collapse at the comminuted sector, and less effective fixation in the metaphyseal fracture. Medullary cortical reaming generates heat during reaming process and sometimes causes heat necrosis and pulmonary embolism of the medullary contents. In addition, better control of the length and rotation of the fragments was necessary to expand the indication of IM nailing to both proximal and distal metaphysis [1–5].

1.2 Second-Generation Nail: Interlocking Nail

Klemm and Schellman (1972)/Kempf et al. (1976) developed the interlocking femoral nails, which could fix the proximal and distal fragments with proximal oblique and distal transverse screws, respectively, and reported their case series. The patients were treated nonweight-bearing in the initial stage of healing to minimize implant failure due to the open section design [6–9]. Russell and Taylor developed the first closed section interlocking nail, which allowed immediate weight-bearing in a static locked configuration with 1% implant failure rate. Grosse and Kempf advocated routine dynamization of the statically locked open section nail after initial callus formation [7, 8]. However, Brumbeck et al.

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maintained the static mode of interlocking until union in most of their cases with a closed section nail [9, 10].

1.3 Third-Generation Nail: Reconstruction Nail

With the expansion of surgical indications of femoral nailing to the metaphysis, inadequate fixation of the proximal femur and screw failure became the main issues of second-generation nails. To fix the femoral neck and head effectively, expansion of the proximal femoral nail body was necessary, just like Gamma (cephallomedullary) nail [1–5]. Combining various screw configurations is possible with complex hole patterns in the proximal portion of the femoral nail in this reconstruction type nail. Krettek et al. made a significant contribution to correcting the malalignment of distal metaphyseal fragments during nail insertion and increasing the strength of nail-screw configuration by adding a Poller screw (blocking screw) beside the nail [11].

1.4 Fourth-Generation Nail

New third-generation femoral nails with better implant material and design facilitate the femoral nailing process with great success. Further scientific progress in polishing techniques enables the attachment of the chemical agents on the surface of the nail. This allows a continuous supply of antibiotics into the wound after nailing, decreasing the risk of infection in open fractures [1–5].

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2 Fracture Healing Mechanism after IM Nailing

2.1 Formation of Hematoma

Fracture results in disruption of blood vessels and hematoma formation within the surrounding soft tissue. The formation of fracture hematoma is essential for the initiation and successful fracture healing process (Fig. 2.1). In the early fracture hematoma, low pH due to disruption of circulation and subsequent anaerobic metabolism is not favorable for cells to survive [1, 2]. However, some immune cells well tolerate these conditions [3]. The rising importance of osteoimmunological

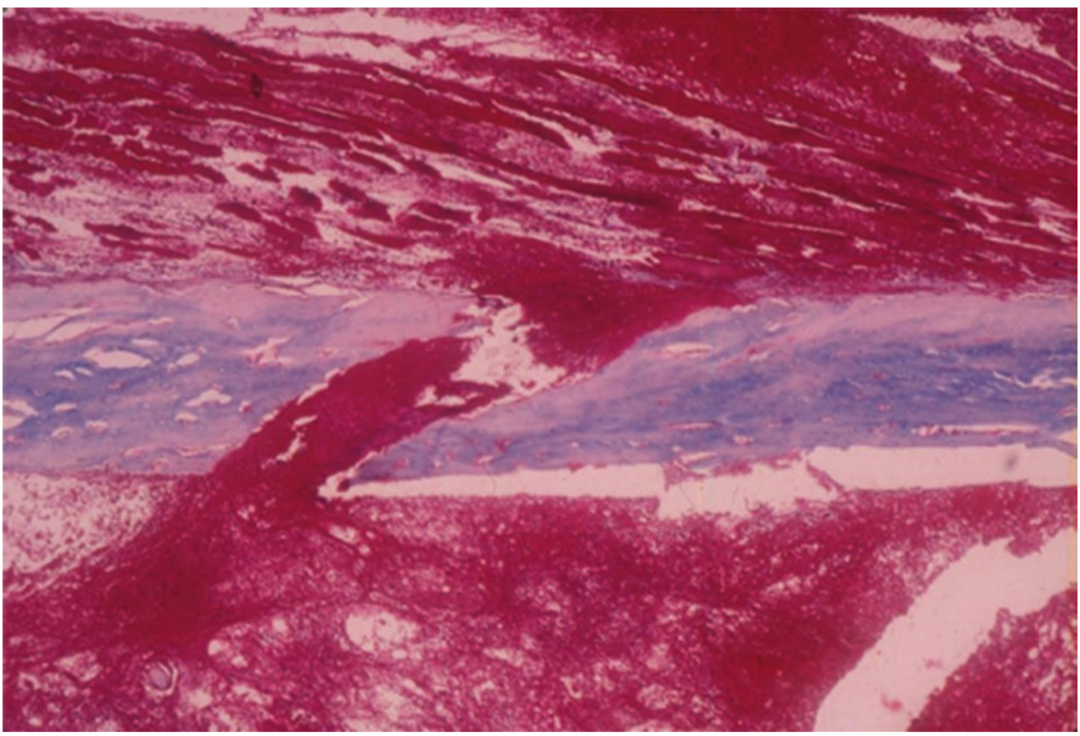

Fig. 2.1 Histology at fracture day 1 in a rat femoral shaft fracture model (Trichrome stain, ×100). Fracture disrupts blood vessels and results in hematoma formation within the surrounding soft tissue. The formation of fracture hematoma is essential for the initiation of callus formation and successful fracture healing process

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aspects in bone healing supports the essential role of the initial hematoma as a source for inflammatory cells that release the cytokines that direct cell recruitment toward the injured tissue. With the onset of inflammation, regeneration begins by migrating mesenchymal stem cells, endothelial cells, and immune cells toward the fracture site [4–6]. It is clear that within the hematoma, there is a bone-forming complex that comprises cells and growth factors including platelet-derived growth factor (PDGF), acidic and basic fibroblast growth factors (aFGF and bFGF), the transforming growth factor-β polypeptide group (TGF-β), and insulin-like growth factor (IGF) [5]. The hematoma serves as a fibrin network for the migration and proliferation of osteogenic and chondrogenic progenitor cells [7]. The progenitor cells originating from the periosteum, the bone marrow, and the surrounding tissue react to the signals sent by the hematoma and migrate into the fracture area thus initiating the soft callus phase of the endochondral bone healing [8, 9].

2.2 Intramembranous Ossification and Endochondral Ossification (Stage of Soft Callus: Unstable)

Intramembranous ossification starts beneath the intact periosteum apart from the fracture site and forms a stable deltoid anchor on both sides of the fracture end. At the end of the torn periosteum, the undifferentiated mesenchymal cells proliferate actively to create a cascade of cells that form cartilage tissue (Fig. 2.2). It is a stage of soft callus and still an unstable situation. Endochondral ossification occurs at the junction of cartilage and trabecular bone formed by intramembranous bone formation [10, 11]. There is a mixture of organizing hematoma and various infiltrating cells at the intermediate zone between the soft calluses. IM nailing violates the medullary circulation, but it increases periosteal circulation, which offers a favorable milieu for callus formation [12].

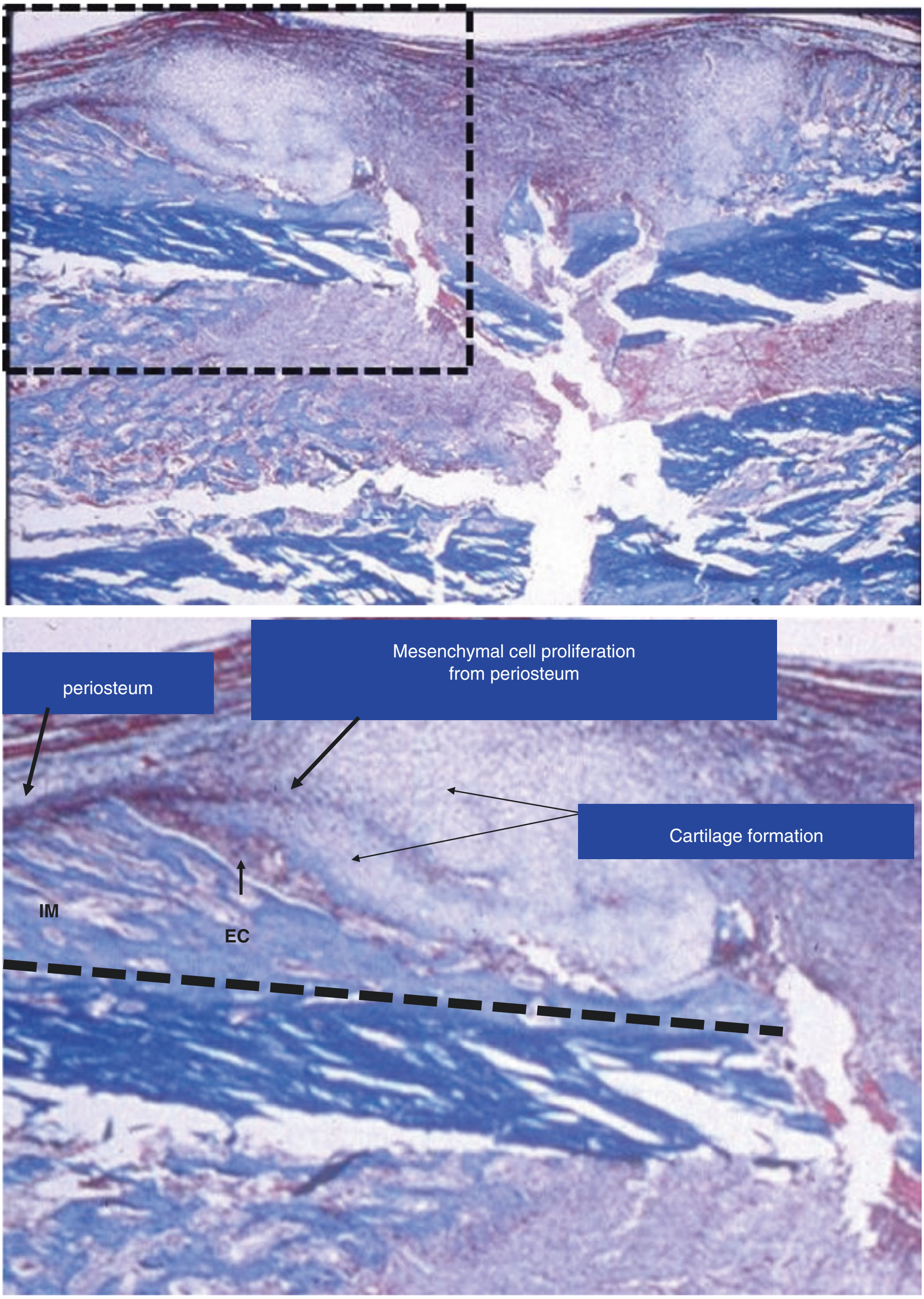

Fig. 2.2 Histology of the soft callus at the fracture site in a rat femoral shaft fracture model (1 week after fracture, Trichrome stain, left, ×100; Lower, enlarged image of the box portion in the upper image) Under the intact periosteum apart from the fracture site, intramembranous ossification starts and forms stable deltoid anchor on both sides of the fracture end. At the end of the torn periosteum, the undifferentiated mesenchymal cells proliferate actively to create a cascade of cells that form cartilage tissue. Periosteal microvessel endothelial cells and pericytes also increased in population and transformed into mesenchymal cells. These mesenchymal cells differentiate into the chondroblasts. Endochondral ossification occurs at the junction of cartilage and trabecular bone formed by intramembranous bone formation. Dot line in the lower image indicates the border between intact cortex and trabecular bone newly formed through intramembranous ossification

2.3 Intramembranous Ossification and Endochondral Ossification (Stage of Hard Callus: Stable)

The progressive replacement of intermediate cartilage tissue by the trabecular bone thorough endochondral ossification resembles a folding fan [12, 13]. At the final stage of the soft callus, a hard bridging callus forms at the periphery of the callus and enters the hard callus stage (Fig. 2.3). The distance (radius of hard callus) between the center of the medullary canal and the thin bridging hard callus is greater than the radius of the outer cortex. Since the cross-sectional moment of inertia increases by a fourth of the radius, the thin hard bridging callus provides sufficient stability for mobilization of adjacent joints. After the complete replacement of cartilage tissue by trabecular bone, the remodeling process starts.

Preservation of hematoma and minimal handling of soft tissues, including periosteum, is a principle of minimally invasive surgery. In this context, IM nailing is an ideal fixation method, as shown in histologic slides (Fig. 2.4).

Bisphosphonate is an antiresorptive osteoporotic drug that interferes with osteoclast activities, so the mineralized cartilage can neither be resorbed nor be replaced by woven bone effectively in endochondral ossification (Fig. 2.5). The callus size increases, but cartilage islands remain in the bony callus. Due to the increase in diameter of the callus, the strength of callus is not compromised despite the poor quality of healing callus. However, it delays the remodeling process later [13].

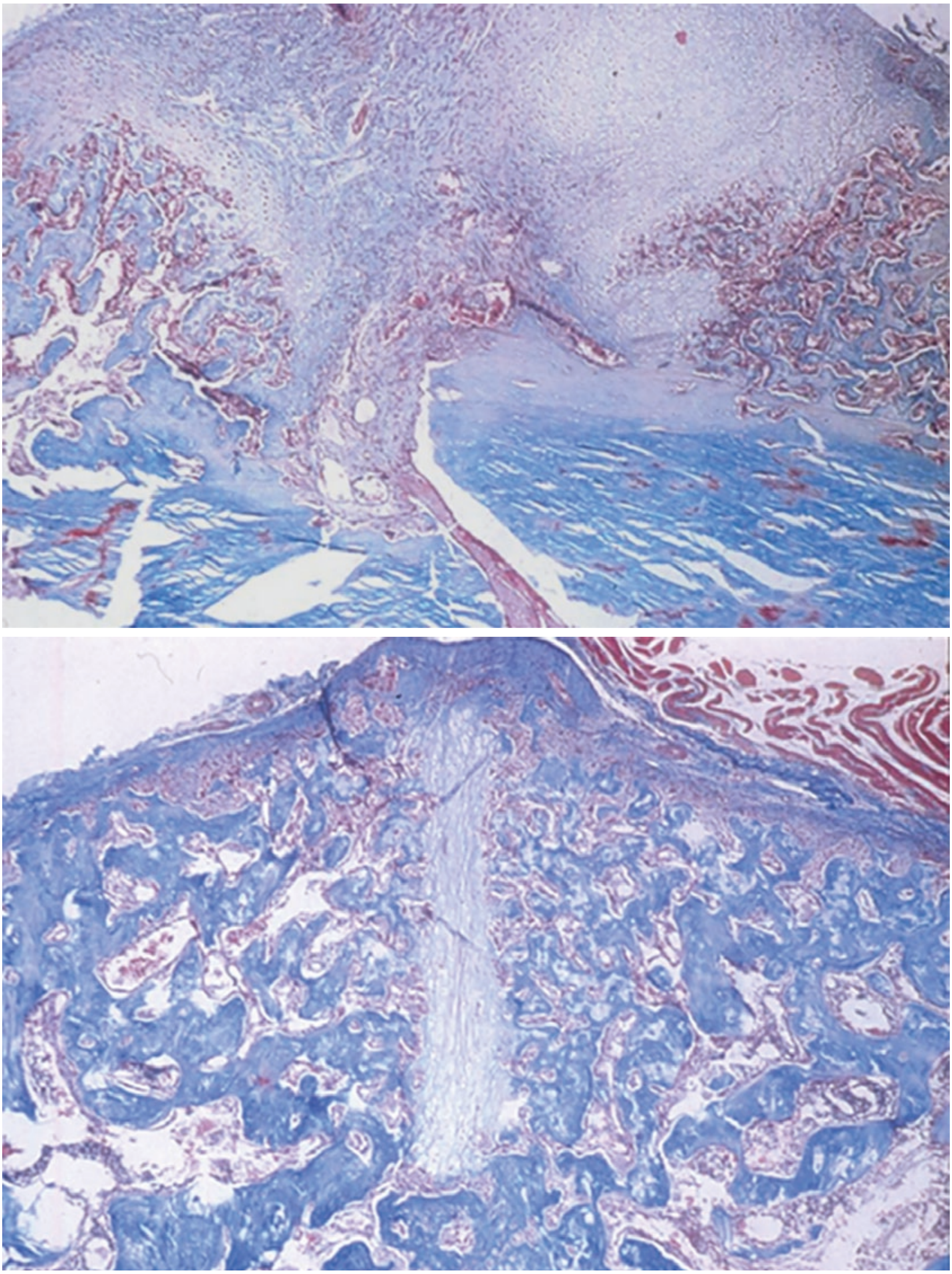

Fig. 2.3 Histology of the callus at fracture 2 weeks (upper) and 3 weeks (lower) in a rat femoral shaft fracture model; Enlarged view of bridging callus formation (Trichrome stain, ×200). The progressive replacement of cartilaginous tissue by the trabecular bone resembles closure of a folding fan (upper). The cartilage tissue finally disappears when the endochondral ossification fronts meet with each other (lower)

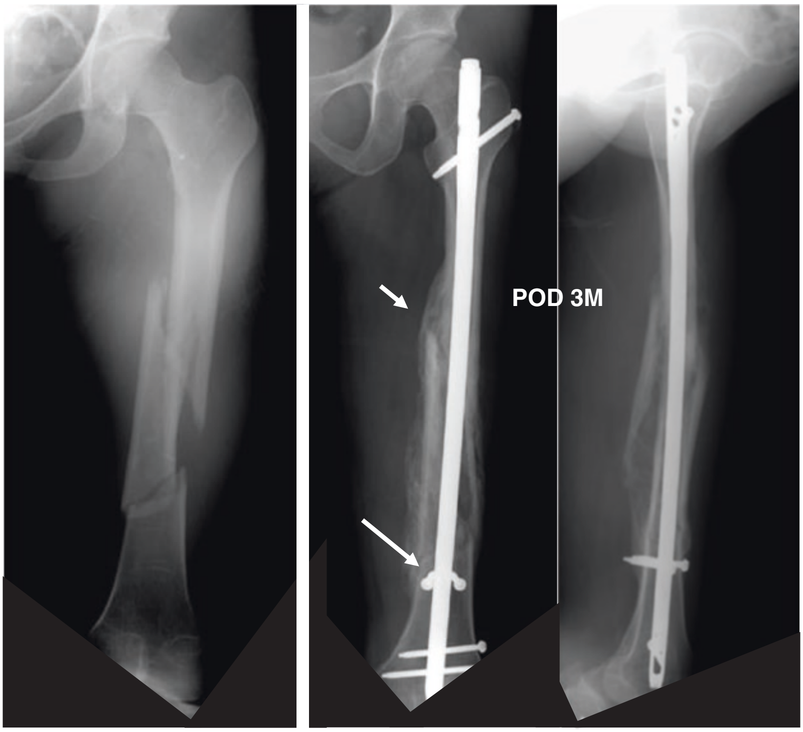

Fig. 2.4 A 22-year-old lady sustained a segmental femoral shaft fracture after a fall at the ski slope. Closed reduction and interlocked IM nailing were performed with two Poller screws (long white arrow) for additional stability of the distal fragment (wide femoral canal). The bridging callus is evident at 3-month postoperative radiograms (short arrow)

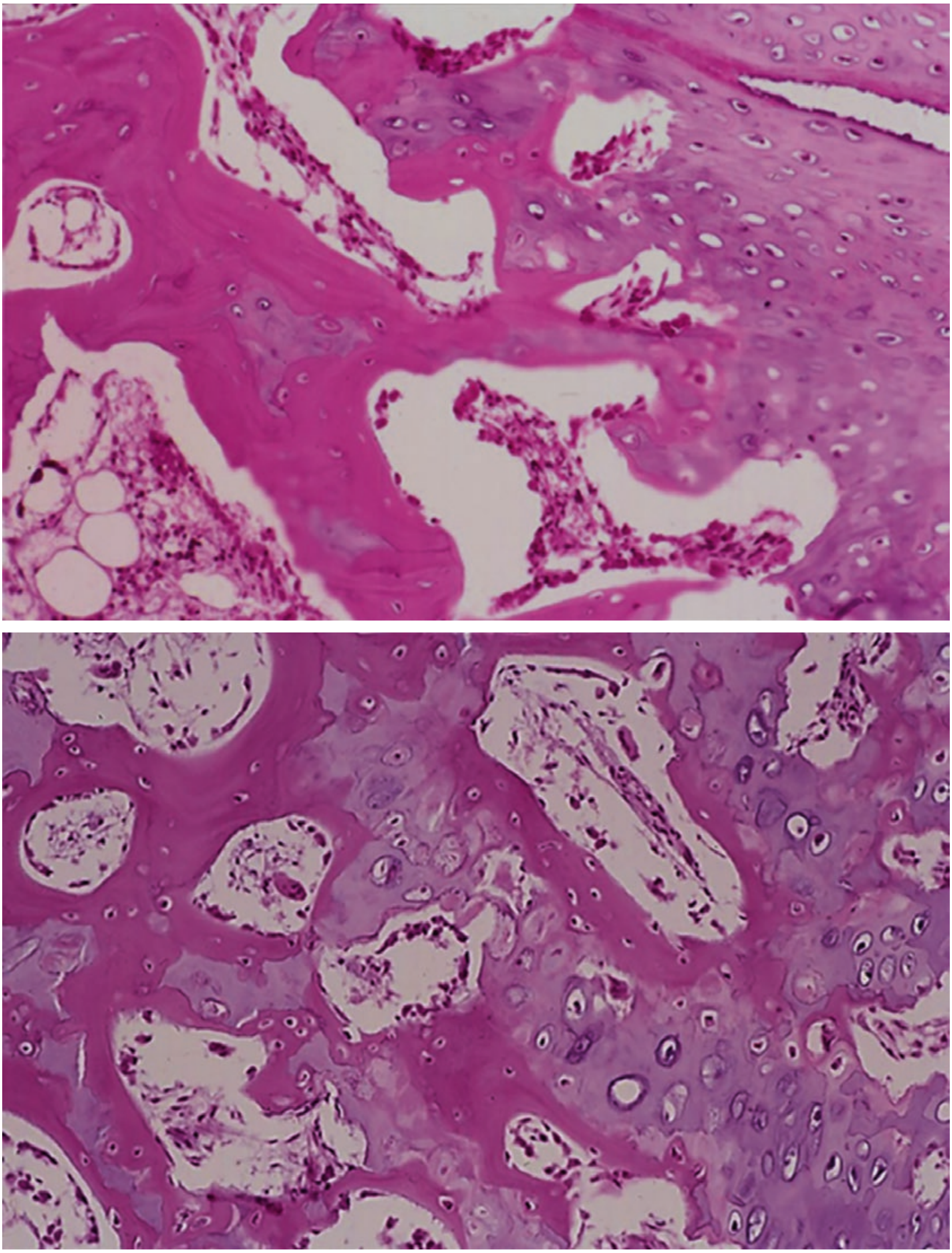

Fig. 2.5 Effect of bisphosphonate (high dose pamidronate) on callus formation in canine tibia fracture model. In normal situations (upper), bone marrow, trabecular bone, woven bone, and cartilage tissue are well separated and visualized (from bottom left to right). Under the influence of bisphosphonate (lower), the mineralized cartilage cannot be effectively replaced by osteoclast and remains in the woven bone until the later stage of remodeling. (Hematoxylin and Eosin stain, ×100)

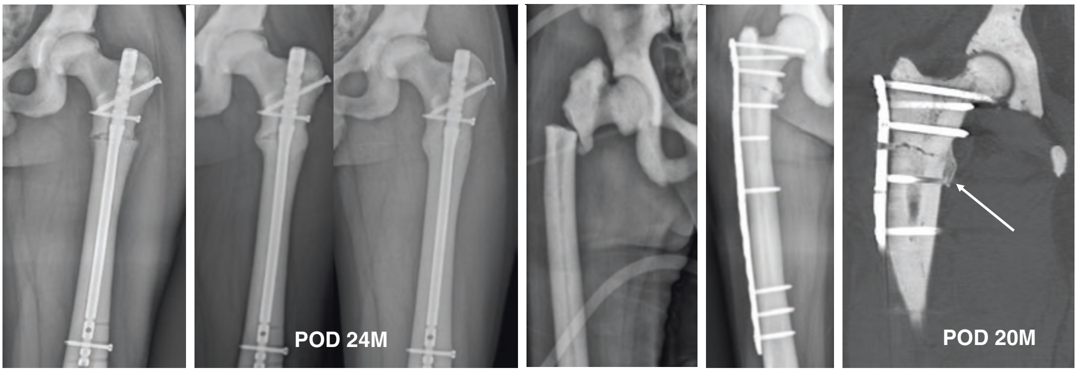

Fig. 2.6 [Left] Callus formation and remodeling of the callus is well depicted in the serial postoperative radiographies in the autosomal dominant type II osteopetrosis patient who sustained a subtrochanteric fracture. The remodeling process in AD II osteopetrosis is slower than normal patient due to deficient osteoclast function. [Right] Deficient remodeling after plate fixation is noted in another autosomal dominant type II osteopetrosis patient. The fracture callus is visible (arrow), but remodeling is not evident 20 months postoperatively [14–16]

2.4 Remodeling

When the stability is achieved by bridging callus, remodeling of the callus starts. The trabecular bone is replaced by lamellar bone by a multicellular remodeling unit. As a result, the callus size shrinks in time and disappears later after IM nailing (Fig. 2.6) [10].

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3 Indication and Contraindication of Femoral Nailing

3.1 Indication

Femoral Shaft Fracture with Various Degrees of Comminution

Closed femoral nailing is a treatment of choice in femoral shaft fractures with various degrees of comminution (Fig. 3.1). The static interlocking method enables us to fix them without risk of collapse at the comminuted segment. It also offers stable fixation for immediate weight-bearing after IM nailing. IM nailing is possible in open fracture after careful, meticulous debridement of the open wound, usually in Gustilo-Anderson classification I and II, sometimes in IIIa (Fig. 3.2) [1–8].

Segmental Fracture of the Femur

Segmental fracture of the femur is another best indication of IM nailing, although it requires high surgical skills (Fig. 3.3). Again, step by step procedure is necessary to overcome the problems encountered [9].

Delayed Union or Nonunion of Femoral Shaft Fracture

Nail conversion after failed plate fixation (Fig. 3.4) and exchange nailing is a popular method to overcome the compromised healing of femoral shaft fracture. For details, see Chap. 9–11 [10–16].

Pathologic Fracture

Certain metabolic bone diseases and tumorous conditions (osteomalacia, osteogenesis imperfect (Fig. 3.5), Paget's disease (Fig. 3.6), hypophosphatemic rickets, fibrous dysplasia, etc.) weaken the femur and cause bowing and even fracture [18–21]. Therefore, prophylactic or therapeutic IM nailing is necessary to let the patients walk on weight-bearing. Deformity of the femur and medullary canal is a contraindication of IM nailing. However, it may be the final solution for a patient who suffers from repeated limb fractures due to osteogenesis imperfect. A metastatic bone tumor is another condition that IM nailing is required for the same purpose (Fig. 3.7).

Reconstruction of Segmental Defect

The IM nail and external fixator combination enables us to correct the leg length discrepancy in a severely injured patient. After correction of the femoral length, a defect can be filled with a simple autogenous bone graft (Fig. 3.8) [23–26] or *Masquelet* technique [27]. For details, see Chap. 7.

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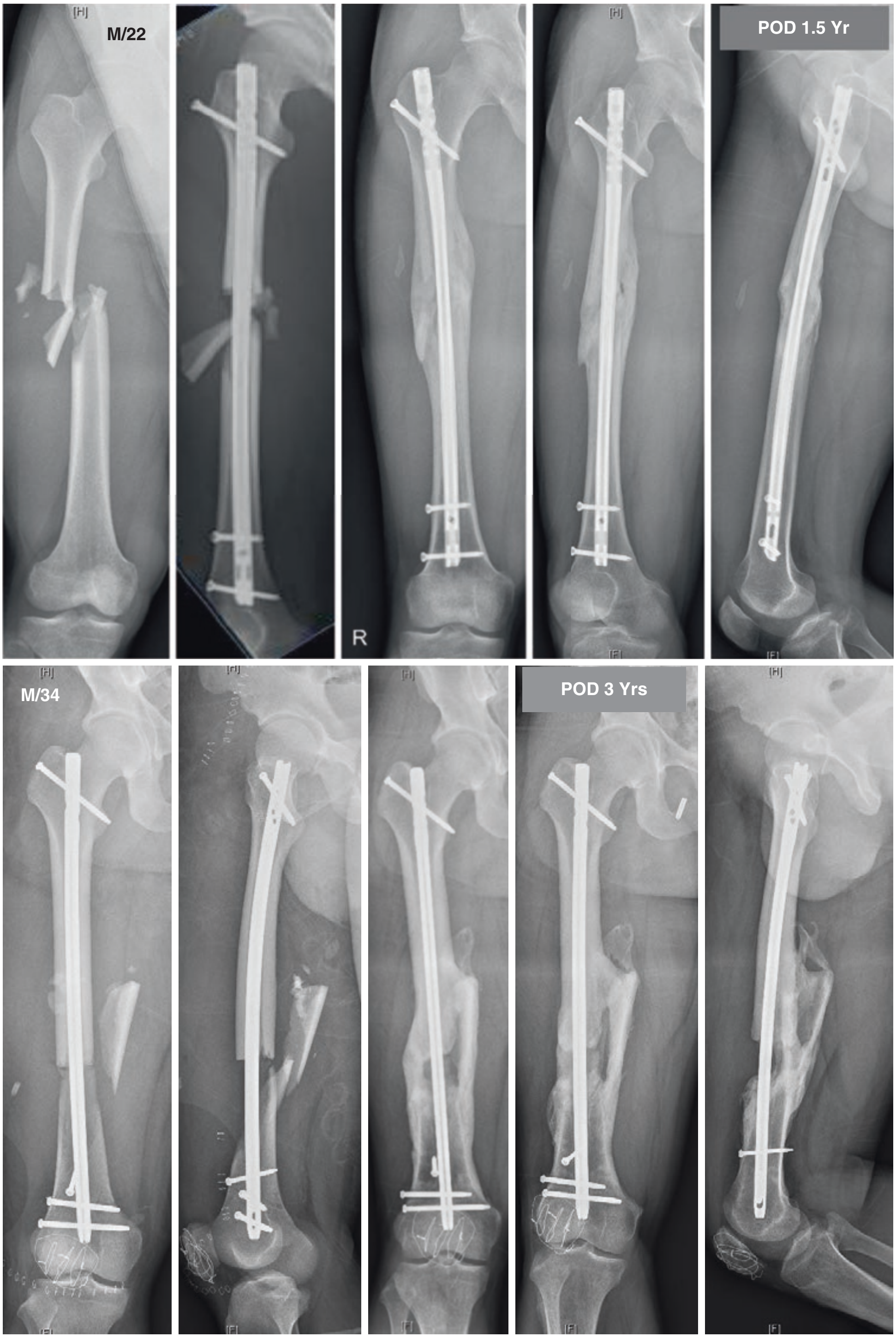

Fig. 3.1 Two cases of severely comminuted femoral shaft fracture. The positions and the situations of the butterfly fragment are different. Although the bone union was obtained in both cases, a large butterfly fragment that was displaced to the other side of the femur should have been reduced by the open technique in the second lower. Bone graft was necessary to fill up the defect before the nail removal in this case

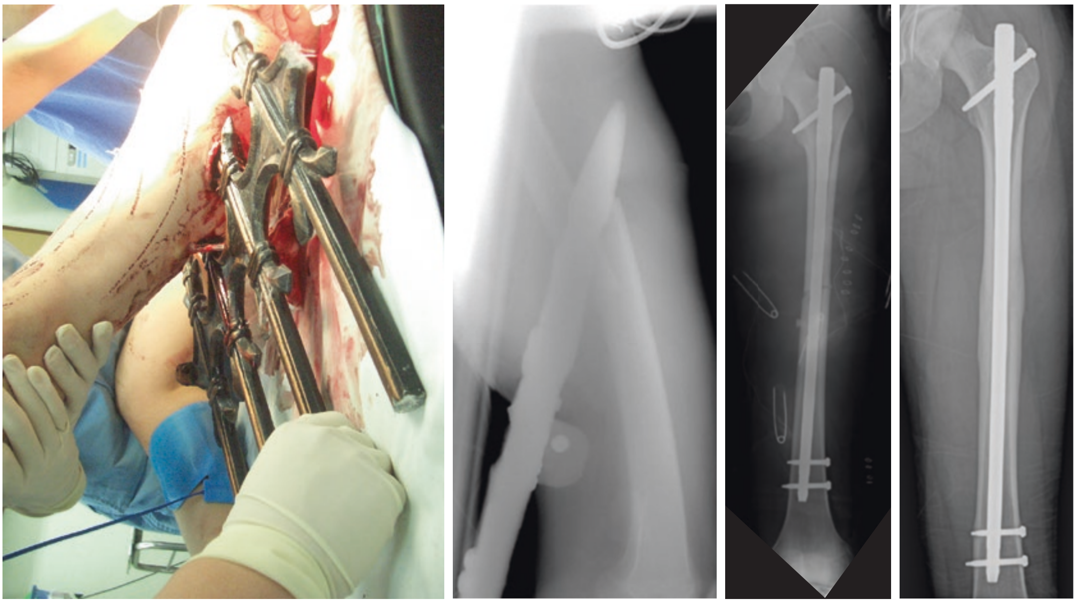

Fig. 3.2 A 20-year-old female patient fell from the second floor through the window. The spear-shaped fence hit her thigh and fractured the femur (left). Sequential radiograms of this patient at the emergency room, operating room (immediate postoperative), and outpatient clinic (final follow-up, right)

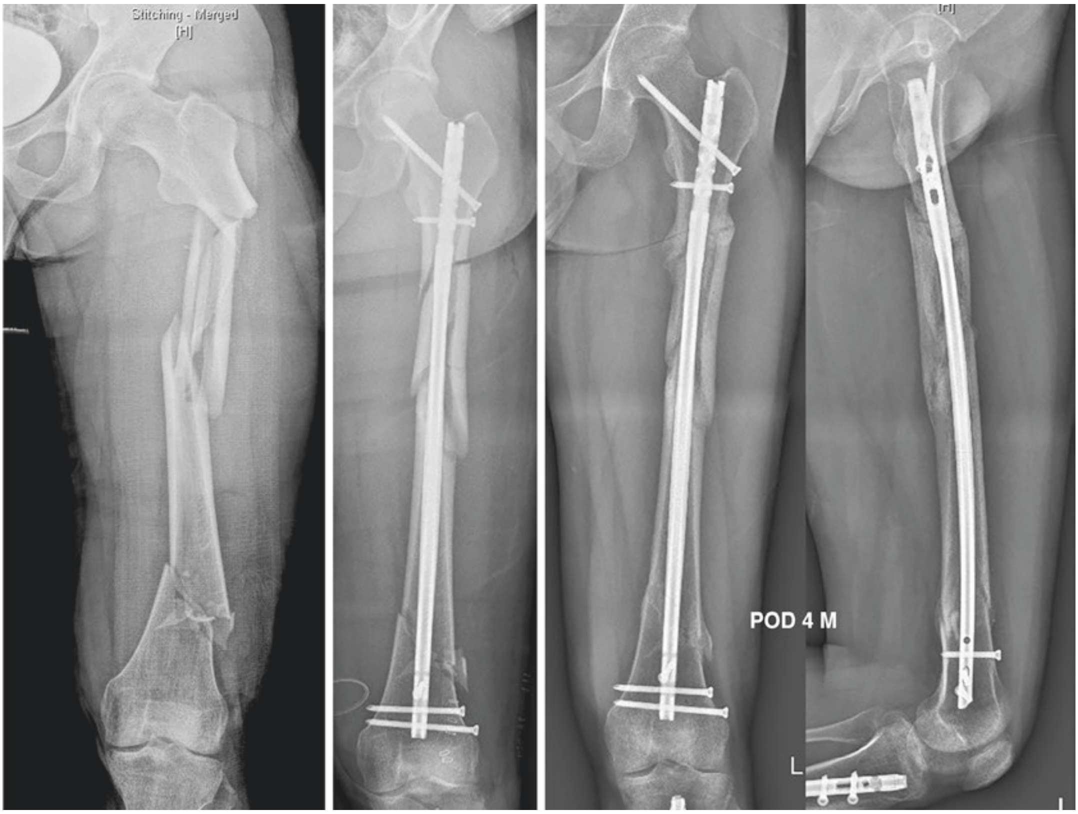

Fig. 3.3 IM nailing is the treatment of choice for segmental femoral shaft fracture if the surgeons have good experiences and techniques to overcome the problems during the IM nailing procedures. Early callus formation is evident after this minimally invasive technique

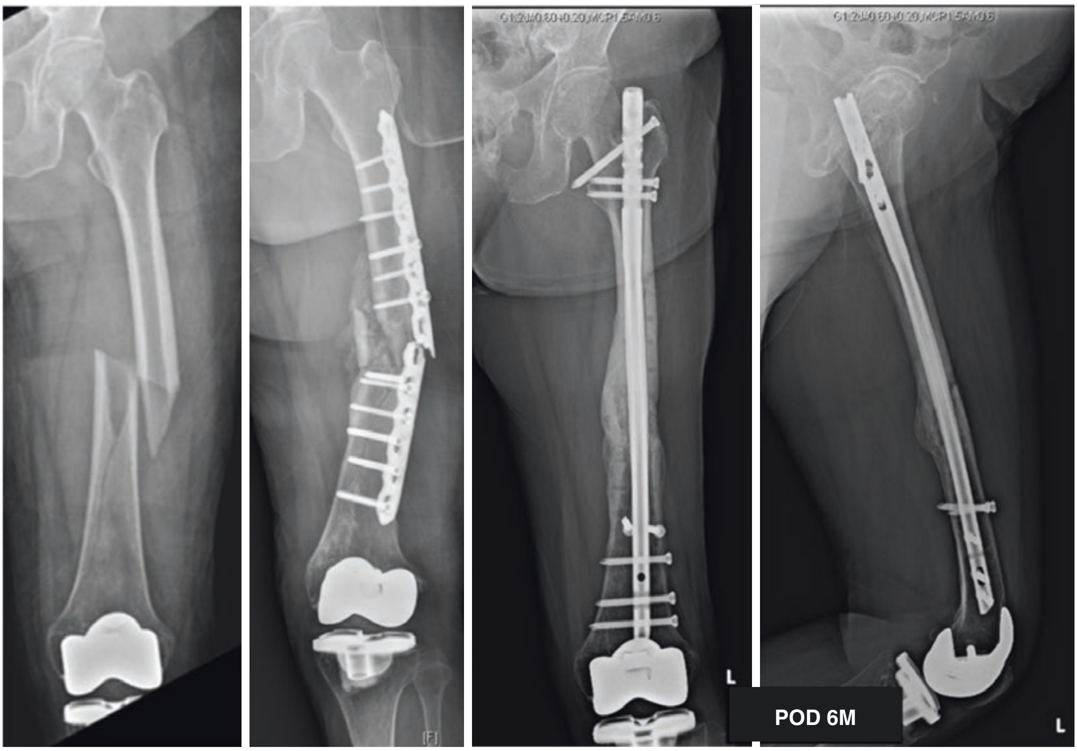

Fig. 3.4 A 77-year-old lady fell from the standing height and sustained a spiral-type femoral shaft fracture. She underwent open reduction and internal fixation with a locking plate at the local hospital. The plate broke 4 months after surgery, and she was transferred to me. A broken plate was removed, and a femoral nail was inserted. Due to weakness of bone after several months of immobilization, three interlocking screws and two Poller screws were used to stabilize the distal fragment. The fracture was united 6 months after nail conversion [17]

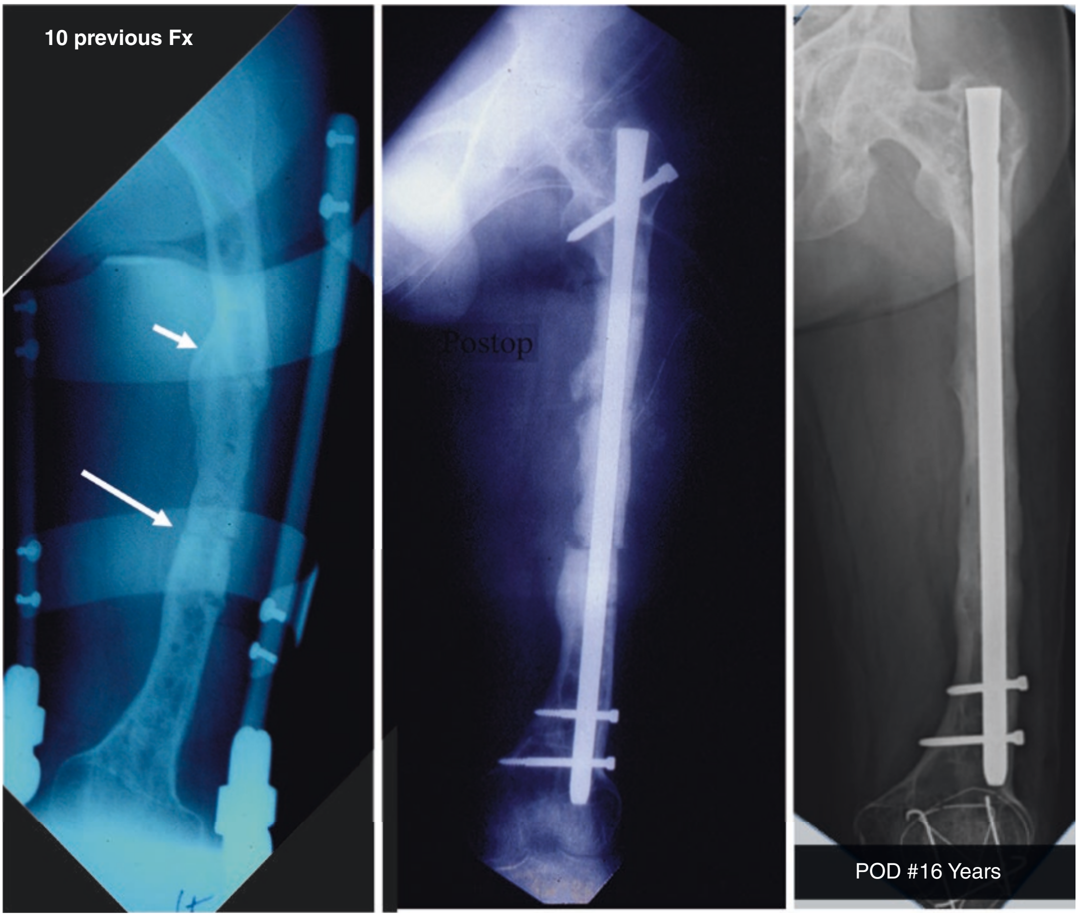

Fig. 3.5 This 30-year-old male patient suffered from 10 previous femur fractures and walked with the support of a long leg brace. He experienced another new fracture at the mid-shaft of the bowed femur after a fall (long white arrow). One of the previous fractures resulted in malunion (short white arrow). Deformity of the femur and associated obstruction of the medullary canal is a contraindication of the IM nailing. However, it could be the only solution in the treatment of osteogenesis imperfect. The Sofield technique is frequently applied to children, but rarely to adults. After osteotomy at the malunion site, IM nailing was performed to straighten the femur. The fracture healed uneventfully, but a proximal interlocking screw was removed due to pain 2 years postoperatively. The femur has been protected from the pathologic fracture for 16 years after the corrective osteotomy and IM nailing

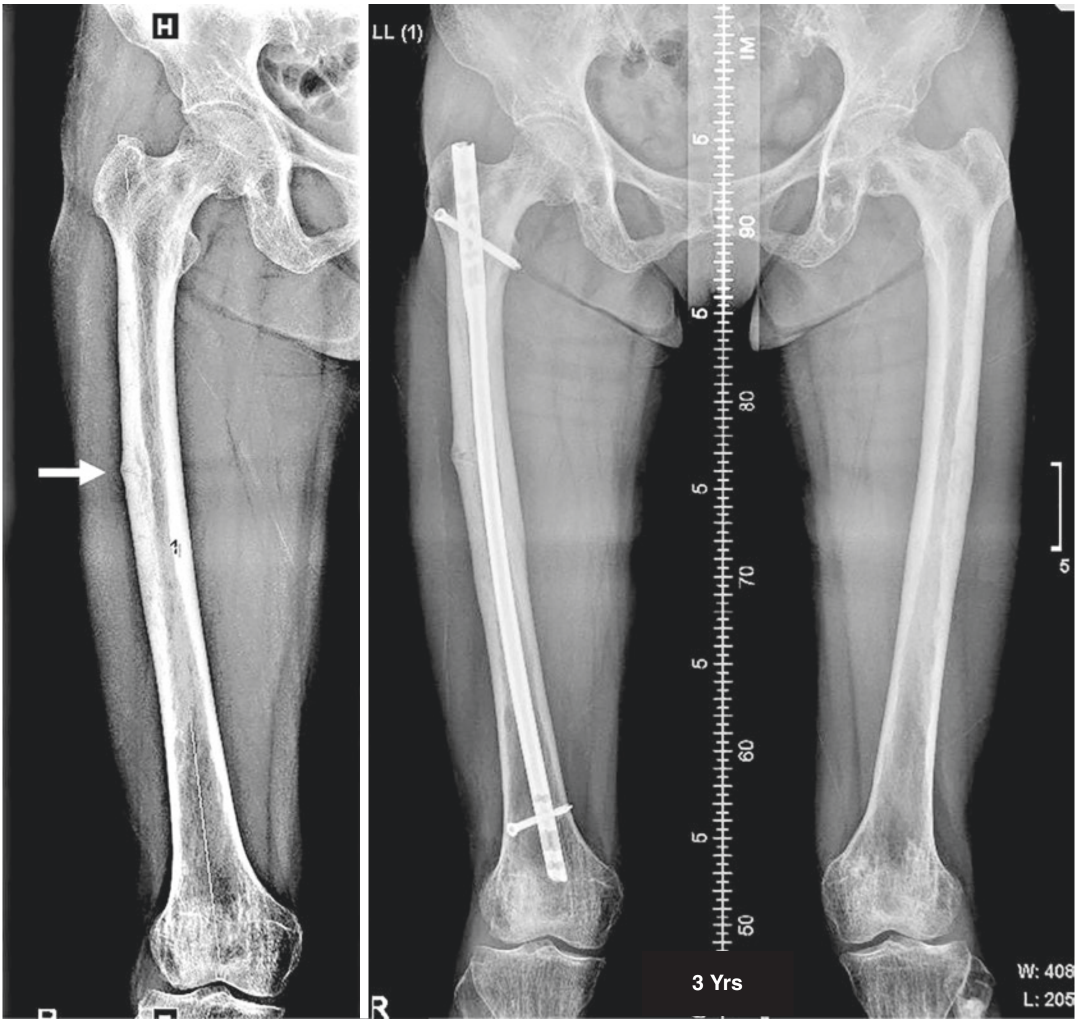

Fig. 3.6 A 66-year-old female patient suffered from Paget's disease on both femora and maxilla. Prophylactic femoral nailing was performed due to progressive bowing, pain, and impending fracture (white arrow). A femoral nail was inserted in external rotation to accommodate excessive anterolateral femoral bowing. Despite the slow healing process of the crack on the femoral bowing apex, the pain subsided 3 years after IM nailing [18, 22]

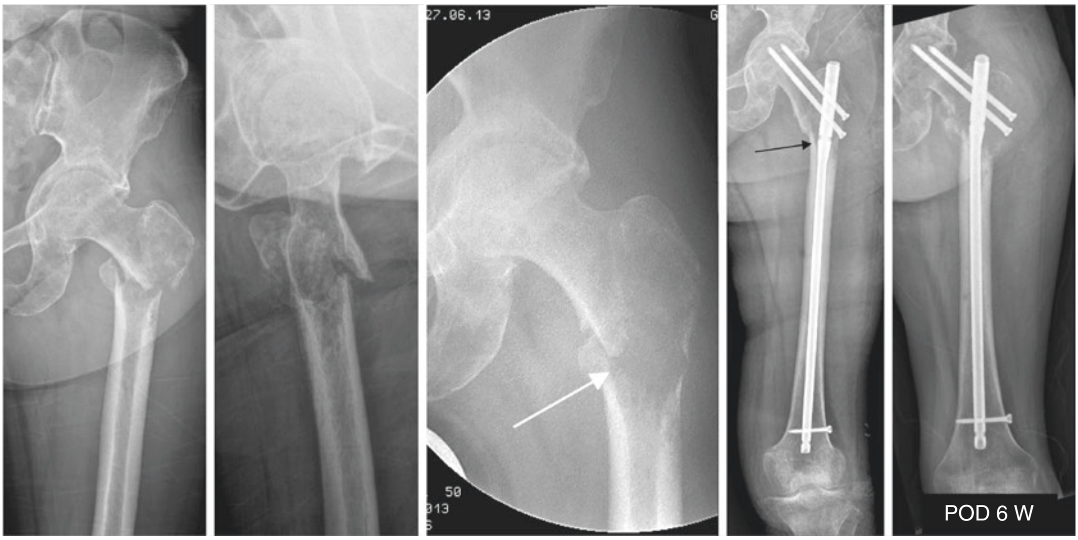

Fig. 3.7 A 60-year-old lady sustained a pathologic subtrochanteric fracture that was caused by a metastatic bone tumor from lung cancer. Intraoperative fluoroscopic image showed a significant void in the subtrochanteric area (white arrow). Because the IM canal was small, it could only accommodate an 8.3 mm diameter femoral nail. In addition, jamming of the transitional part of the nail (black arrow) interfered with proper insertion of the proximal interlocking screws into the femoral head. Further destruction of the trochanter was noted 6 weeks after IM nailing

Lengthening of Femur

Shortening of the femur after the injury is a serious complication that results in limping and back pain due to scoliosis. Specially designed nails with rachets inside can increase the length of the nail and interlock the femur to correct leg length discrepancy (Fig. 3.9). The outcomes of motorized intramedullary lengthening nail are good with acceptable complication rates [28, 29]. For details, see Chap. 12.

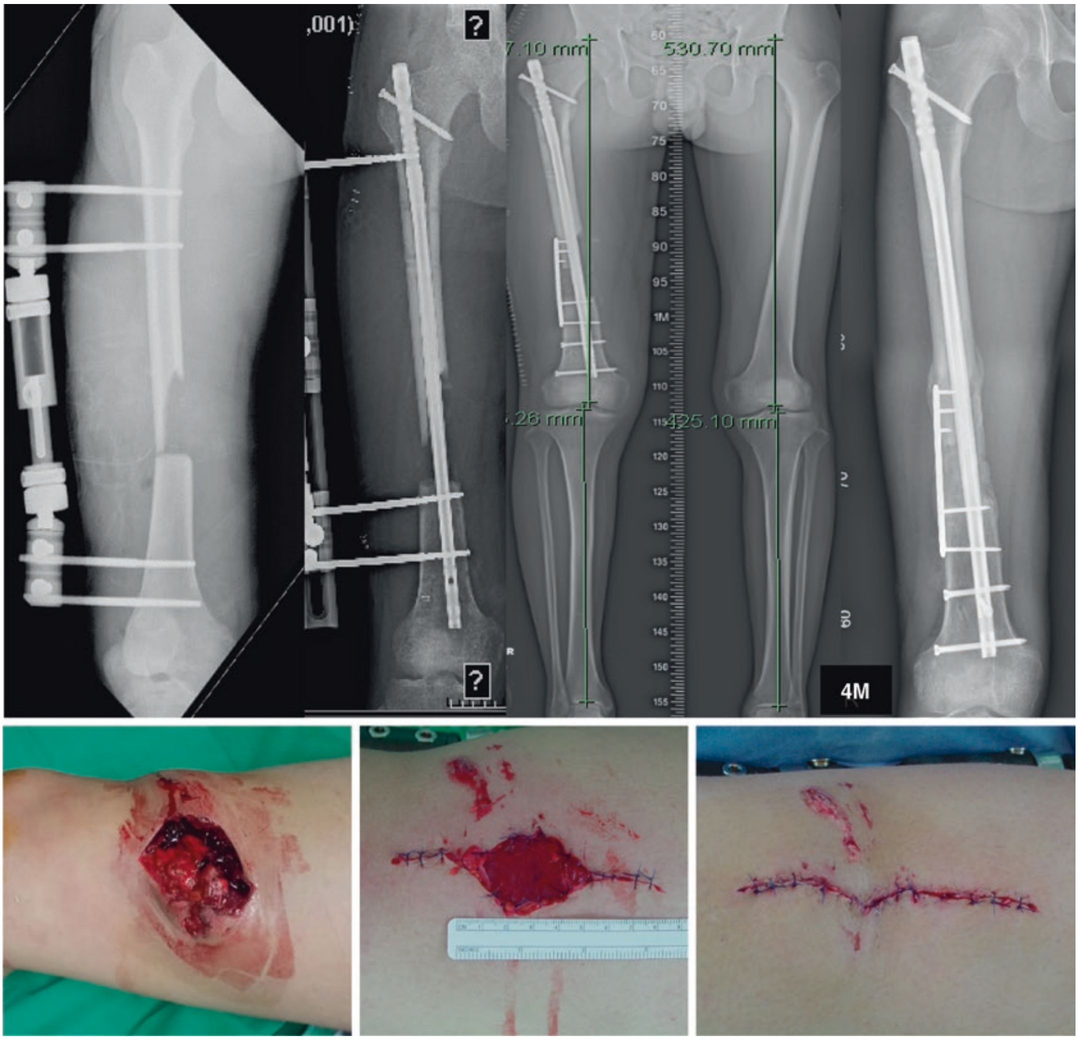

Fig. 3.8 A 19-year-old boy sustained an open femur shaft fracture after a motorcycle accident. Segments of bone were missing through the open wound. An external fixator was applied after debridement at first. Due to the shortening of the femur, primary closure of the open wound was possible after debridement (lower column). Two weeks after injury, the femur was fixed with IM nail and augmented with a Monorail type of Orthofix external fixator. The gradual lengthening of the femur was performed until the length of the injured femur matched with an intact side. Then, distal interlocking of the femoral nail and autoiliac bone graft was performed. Augmentative lateral plate fixation was an operating surgeon's discretion. Bone union is evident at postoperative 4 months

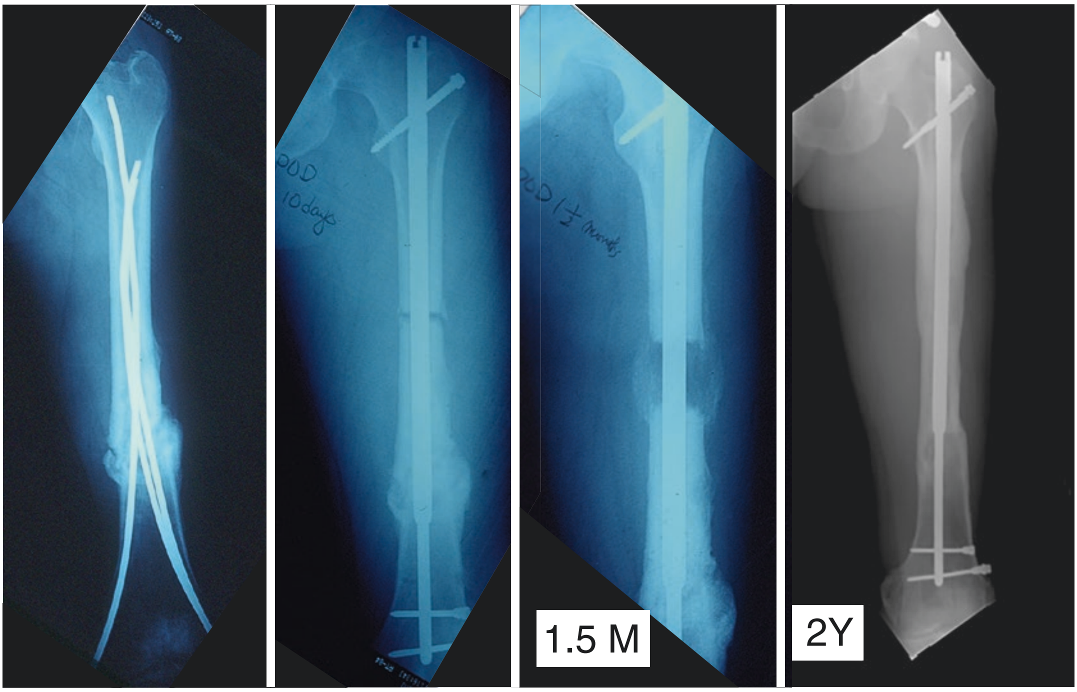

Fig. 3.9 Fixation of femoral shaft fracture with the Ender nail resulted in bony union with shortening of 6 cm. The shortened femur was osteotomized using the IM saw and fixed with an Albizzia nail. Gradual lengthening was performed after 2 weeks, and early callus formation was evident at postoperative 1.5 months. The lengthened part was completely remodeled at postoperative 2 years

3.2 Contraindication

1. Active infection: Active infection is a contraindication of osteosynthesis with an internal implant, such as nail and plate.
2. Narrow medullary canal; Obliteration or excessive narrowing of the medullary canal is a contraindication of IM nailing (Figs. 3.10 and 3.11).
3. Deformity of the medullary canal due to previous injury.

   Severe deformity of the long bone precludes IM nailing unless correctional osteotomy is performed before the nailing (Fig. 3.12). For IM nailing in deformed femur, see Chap. 11 [33].
4. Severe lung injury in a multiple injured patient [34–38].

   The reamer head acts as a piston within a syringe. So, the rapid advancement of the reamer head causes high IM pressure and pulmonary embolism of the medullary contents, which is critical in severe lung injury (Fig. 3.13).

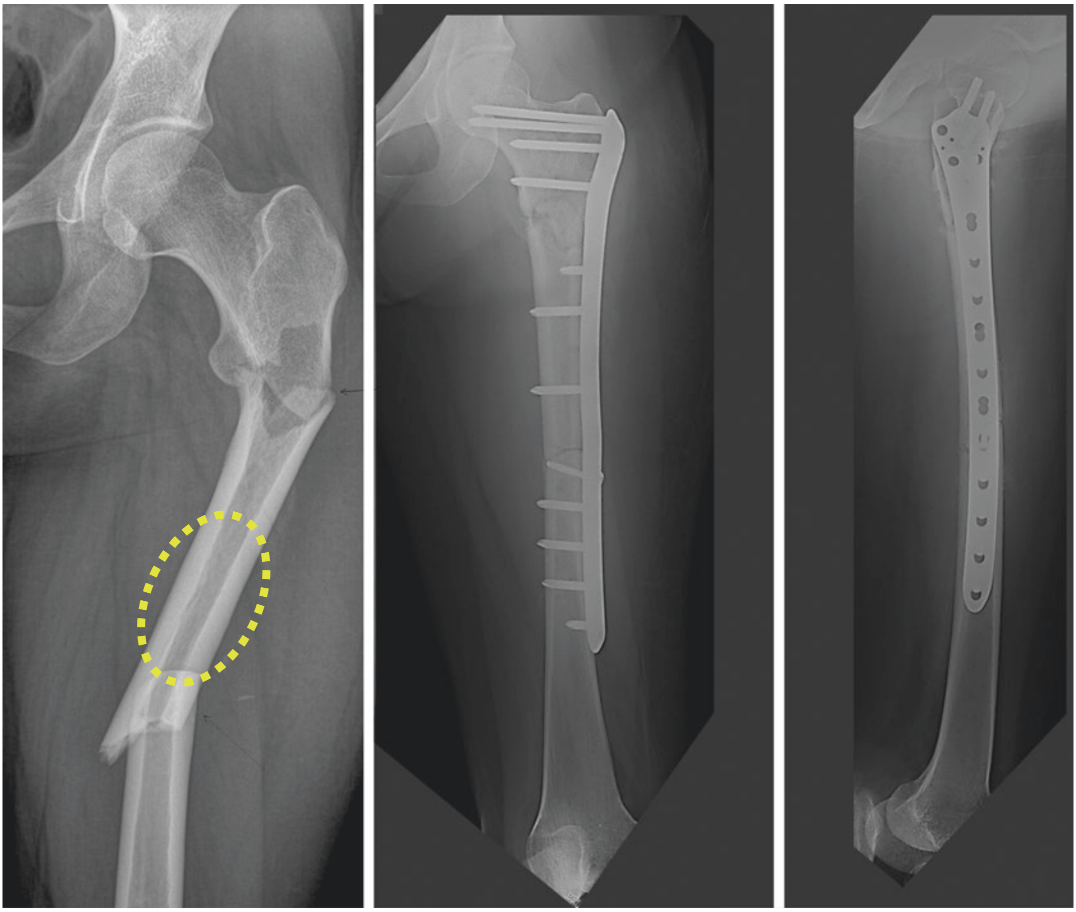

Fig. 3.10 An extremely narrow medullary canal in the middle segment of the segmental femoral shaft fracture precluded IM nailing because of the fear of spinning the middle segment, heat necrosis, and fat embolism during IM reaming. Therefore, osteosynthesis was performed using MIPO technique instead

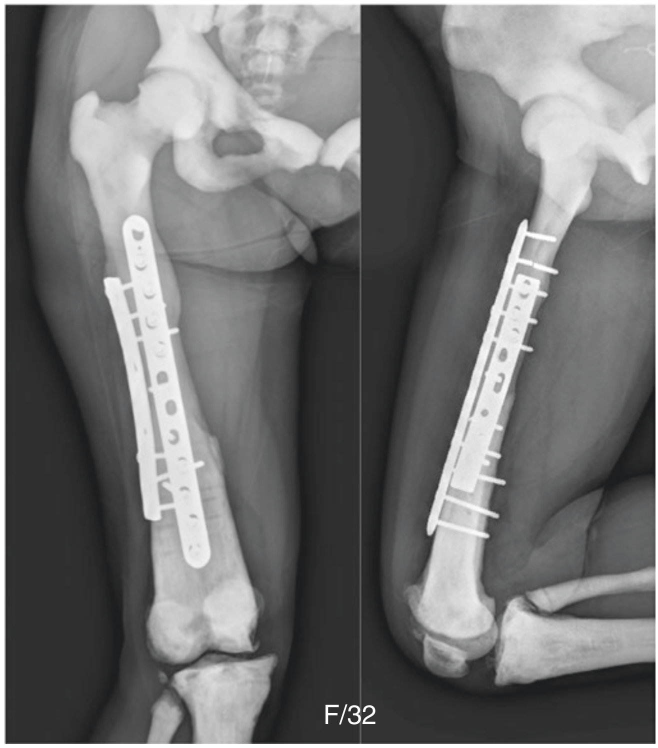

Fig. 3.11 A case of osteopetrosis with an extremely narrow medullary canal. It is wise to avoid IM nailing if the medullary canal is not traceable [30–32]

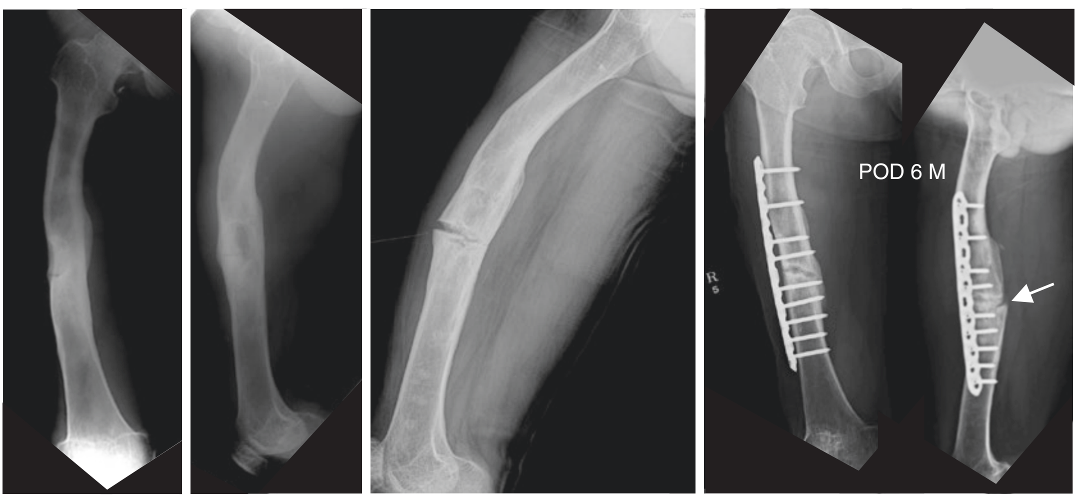

Fig. 3.12 The locking plate for the complex deformity in the femoral shaft. The patient had complex deformity at the femoral shaft and sustained an insufficiency fracture at the distal zone of the deformity. We aligned the straight portions of both proximal and distal fragments and attached the locking plate and screws from the lateral aspect of the femoral shaft. It mimicked as if we performed a correctional opening osteotomy. The fracture site and posterior opening gap (white arrow) were healed 6 months after plate osteosynthesis. A locking plate is a useful tool in fixing the irregular surfaces of the femoral shaft. Otherwise, tightening of the conventional screw pulls the cortex to the undersurface of the plate, interfering with open osteotomy effect

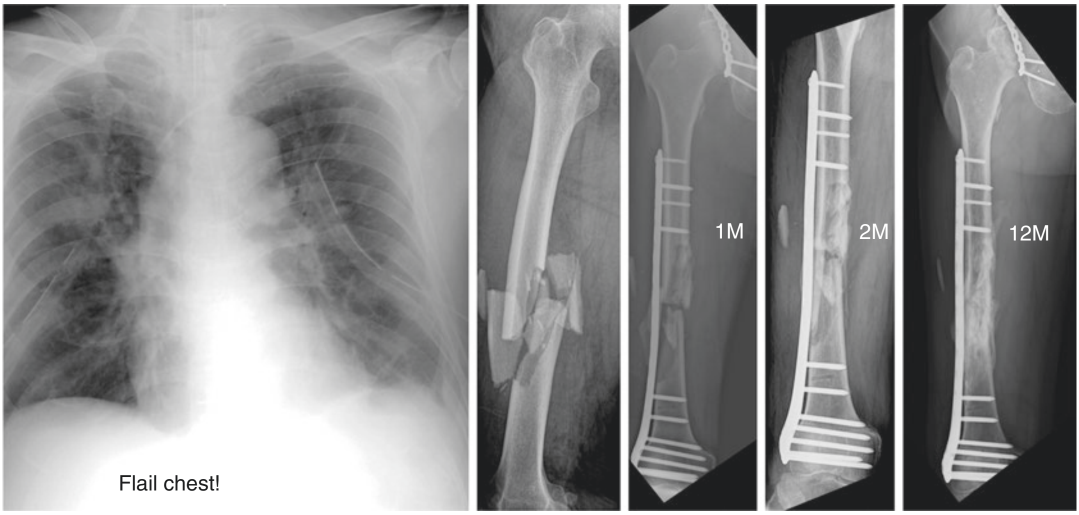

Fig. 3.13 IM nailing in a multiply injured patient with severe lung injury may aggravate the lung function due to embolization of the marrow contents. The chest tubes were inserted in both sides of the pleural cavities to treat the flail chest. MIPO technique was used to treat the severely comminuted femoral shaft fracture. Union was obtained 12 months after the operation

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4 Antegrade Femoral Nailing for Femoral Shaft Fracture

4.1 Position of the Patient

IM nailing for femoral shaft fracture can be performed in supine or lateral position under general or regional anesthesia. Even though preparation time may increase, positioning the patient on the fracture table in a supine position is the most popular method because the maintenance of steady traction is the most crucial point in closed reduction, reaming process, insertion of the nail, and distal interlocking, especially in highly comminuted fracture (Figs. 4.1, 4.2, and 4.3) [1]. The biggest drawback of this position is difficulty in making proper piriformis entry (*trochanteric fossa*—see below) in some patients. The bulky soft tissue in obese patients, narrow space between the greater trochanter and iliac crest in the small patients, and overhanging of the greater trochanter over the trochanteric fossa are the sources of trouble [2, 3]. The contralateral limb can be placed on the leg holder for free access for the image intensifier (hemi-lithotomy position); however, prolonged operation time and low diastolic pressure may evoke *compartment syndrome of the leg* [1]. In that case, the scissoring leg position is advocated. Some surgeons prefer lateral position on the fracture table, especially in subtrochanteric fracture. Flexion of the hip makes it possible to find an unobstructed route to the entry site without difficulties [1, 4].

Fig. 4.1 Preparation of patient on the fracture table in a supine position. Adduction of the injured limb is necessary to approach the entry point (trochanteric fossa). Abduction/flexion of the contralateral limb provides the free space for fluoroscopy

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https://doi.org/10.1007/978-981-19-3730-9_4

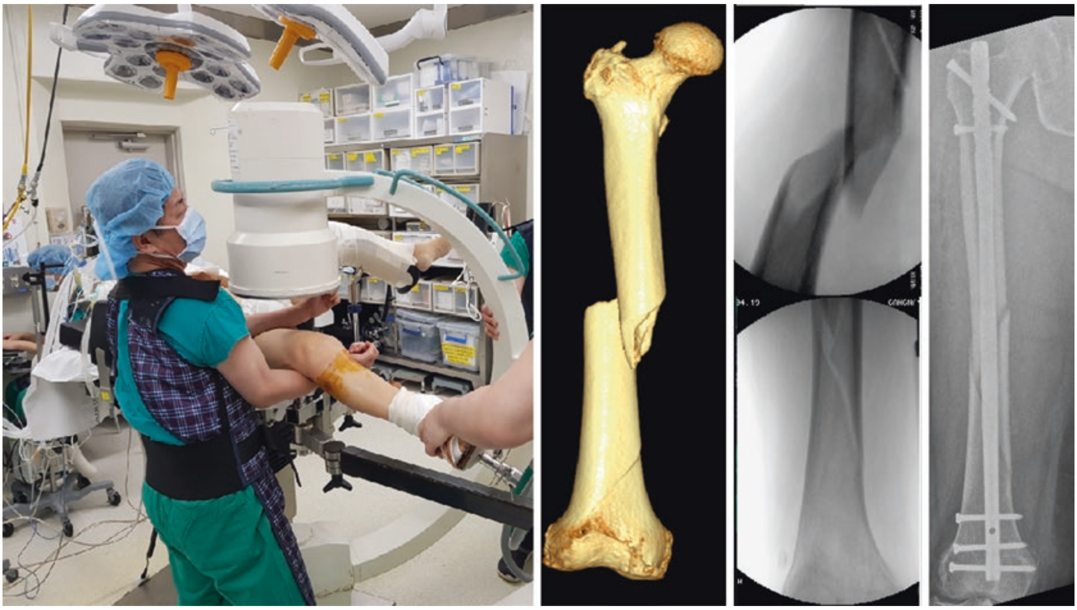

Fig. 4.2 Closed reduction of a spiral fracture before positioning the patient on the fracture table. After placing the patient on the fracture table, check out the fracture site with fluoroscopy. The entire femur must be visualized without obstruction in AP and lateral views. When the leg is fixed on the fracture table, it is challenging to reduce a spiral fracture during the IM nailing process. If the distal fragment is displaced into the femur's other side, the leg and footplate are released from the fracture table. Then, the injured limb is mobilized in circumduction (counterclockwise rotation of leg, in this case, left figure) for reduction. After closed reduction, refix the footplate to the fracture table and confirm the alignment

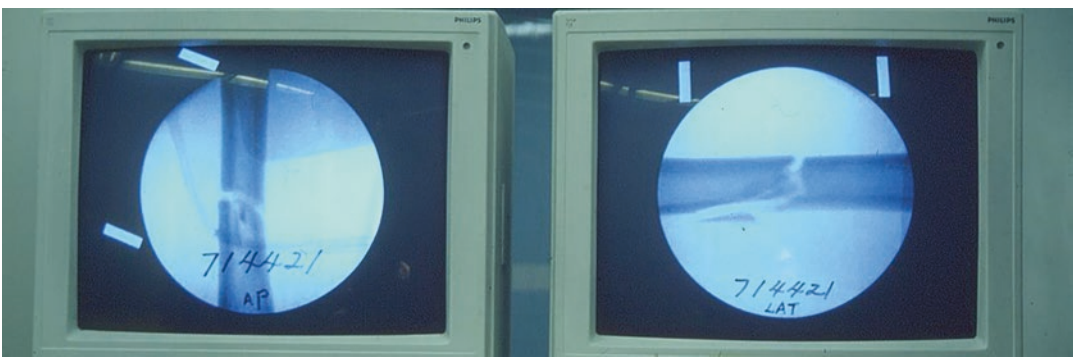

Fig. 4.3 Final adjustment of leg position before incision. Align the injured limb with reasonable traction force to align the fractured femur in AP and lateral view before starting IM nailing. If you find some differences in cortical thickness between proximal and distal fragments, think about the malrotation and correct it. It dramatically facilitates IM nailing when you get a proper alignment because it guarantees free passage of a ball-tip guidewire, reamers, and a nail. Slight over-traction is acceptable because traction can be released once the nail enters the medullary canal of the distal fragment for a few centimeters. The gap would disappear. If not, counter-tract the distal thigh and knee while the nail advances

4.2 Entry Point (for the Straight Femoral Nail)

Defining the appropriate entry point is a problematic issue in antegrade femoral nailing. Nowadays, most surgeons agree that the ideal entry site is a proximal exit of the bisecting line of the medullary cavity of the femur. Küntscher inserted the straight open section cloverleaf nail from the tip of the greater trochanter, namely the *piriformis fossa*. The piriform fossa is an insertion site of the piriform tendon and represents a slight, shallow depression located on the tip of the greater trochanter. The tip of the greater trochanter was used as an entry point to avoid possible violation of blood supply to the femoral head and septic arthritis following intracapsular infection at that time [5–8]. However, over one-half of the cases show that insertion of the straight femoral nail from *the tip of the greater trochanter* (GT, X in the Fig. 4.4) may result in lateral insertion. Lateral insertion of the stiff straight femoral nail is detrimental in some cases (Fig. 4.4a and b), resulting in varus tilting of the proximal fragment and bursting of the medial cortex of the proximal fragment and fracture of the greater trochanter (Fig. 4.5) [2, 3].

As a result, the surgeons sought more medial entry sites, namely trochanteric fossa, to avoid lateral insertion in these cases (Fig. 4.4a and b). The proximal exit of a bisecting line of the medullary canal passes around *the trochanteric fossa*. The trochanteric fossa is a deep depression on the inner surface of the greater trochanter and represents the insertion of the obturator externus muscle. Contrary to the concern during the early development of IM nailing, the use of trochanteric fossa as an entry point in *adult* femoral nailing does not violate the circulation of the femoral head. *These days, people agree that the trochanteric fossa is an appropriate entry point for antegrade femoral nails in adults*. Many surgeons have shifted the entry site from the tip of the greater trochanter (piriformis fossa) to the trochanteric fossa for mechanical reasons. They, however, have kept using the term "piriform entry" incorrectly in many published articles (Fig. 4.6) [2, 3, 6].

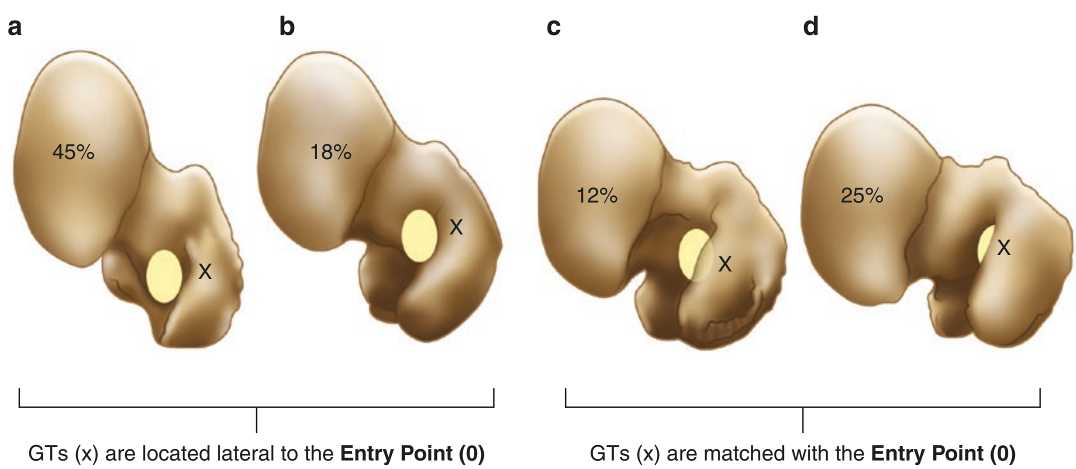

Fig. 4.4 Photographs showing the overhang of the greater trochanter at the site of insertion. From a cranial view, it was graded into four groups: group (**a**) specimens offer full access to the entry point (white circle); group (**b**) specimens are defined by a laterally projecting spine; group (**c**) specimens have a partially covered entry point; and group (**d**) specimens have a completely covered entry point. Relationship between the tip of the greater trochanter (X) and trochanteric fossa (white circle). A mismatch is shown in Group (**a**) and (**b**). Insertion of the straight nail from the tip of the greater trochanter may result in lateral insertion in these groups

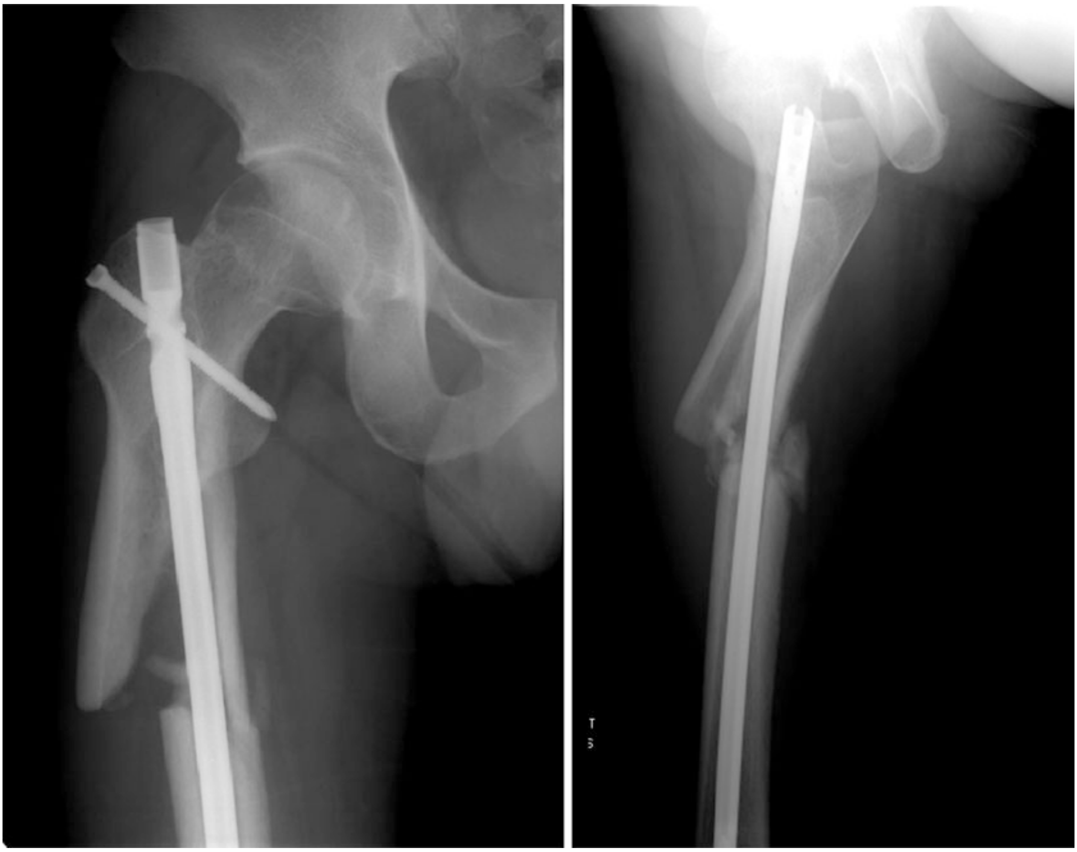

Fig. 4.5 Lateral insertion of the straight femoral nail resulting in varus tilting of the proximal fragment and the fracture of the medial cortex

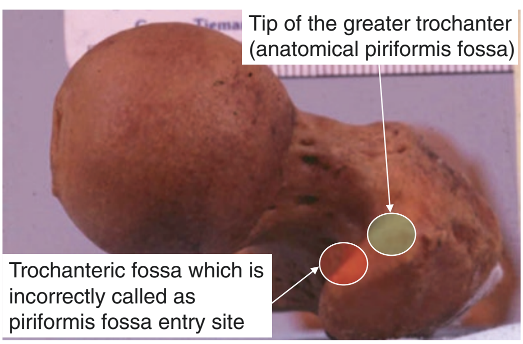

Fig. 4.6 Relationship between piriformis fossa and trochanteric fossa. Many surgeons have shifted the entry site from the tip of the greater trochanter (anatomical piriformis fossa; green circle) to the trochanteric fossa for mechanical reasons. The trochanteric fossa is a deep depression on the inner surface of the greater trochanter and represents the insertion of the obturator externus muscle (red circle). In many published articles, people kept using the term "piriform entry" incorrectly to describe the entry point (trochanteric fossa)

The chief problem in using trochanteric fossa as the entry point is hiding of entry point by an overhang of the greater trochanter in some cases (Fig. 4.7). External rotation of the proximal fragment, especially in subtrochanteric fracture, aggravates the situation. The greater trochanter starting femoral nails have been developed and released in the twenty-first century to overcome these problems. P*reoperative planning is important in selecting the proper entry point for the intended use of the femoral nail; piriformis fossa* (it is a misnomer; trochanteric fossa is correct) vs. *greater trochanter* starting femoral nail.

Since the tip of the greater trochanter is easily palpable through the surgical incision, I would focus on preparing the entry point on the trochanteric fossa in this chapter. If the patient is prepared on the fracture table in a supine position, adduction of the injured limb and deviation

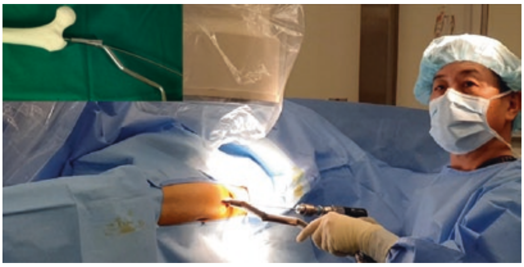

Fig. 4.7 Technique to solve the problem of an overhang of the greater trochanter over the trochanteric fossa. The use of an outer sheath of separable awl or similar equipment (inlet) makes it possible to bend the end of the guide pin outward to face toward the center of the medullary cavity. This technique is handy in the cases of an overhang of the greater trochanter (Group C and D in Fig. 4.4), obese patients, and small patients whose working space between the greater trochanter and the iliac crest is narrow. The amount of bending is controllable while watching the fluoroscopic images. The best entry point is where the imaginary bisecting line of the medullary canal exits in both hip AP and lateral images. It is usually around the "trochanteric fossa," which is frequently referred to as "piriformis entry" incorrectly

of the trunk to the intact side is necessary. However, excessive adduction tightens the lateral fascia and iliotibial band, making it difficult to palpate the deeply seated trochanteric fossa [6]. Under the guidance of a fluoroscope, the tip of the guide pin is inserted into the medial aspect of the greater trochanter. If the tip of the guide pin is located in the superior part of basi-cervical region in the hip AP view, it is located too anterior and vice versa. In some cases, the trochanteric fossa is visible in the fluoroscopic image (Fig. 4.8).

Suppose external rotation of the proximal fragment hinders the proper evaluation of the anatomy. In that case, you may insert the long curved hemostatic forceps at the level of lesser trochanter through a small stab wound on the posterolateral aspect of the thigh. Elevation of the handle of hemostatic forceps rotates the proximal fragment internally and visualizes the greater trochanter's medial aspect clearly. It was a great discovery

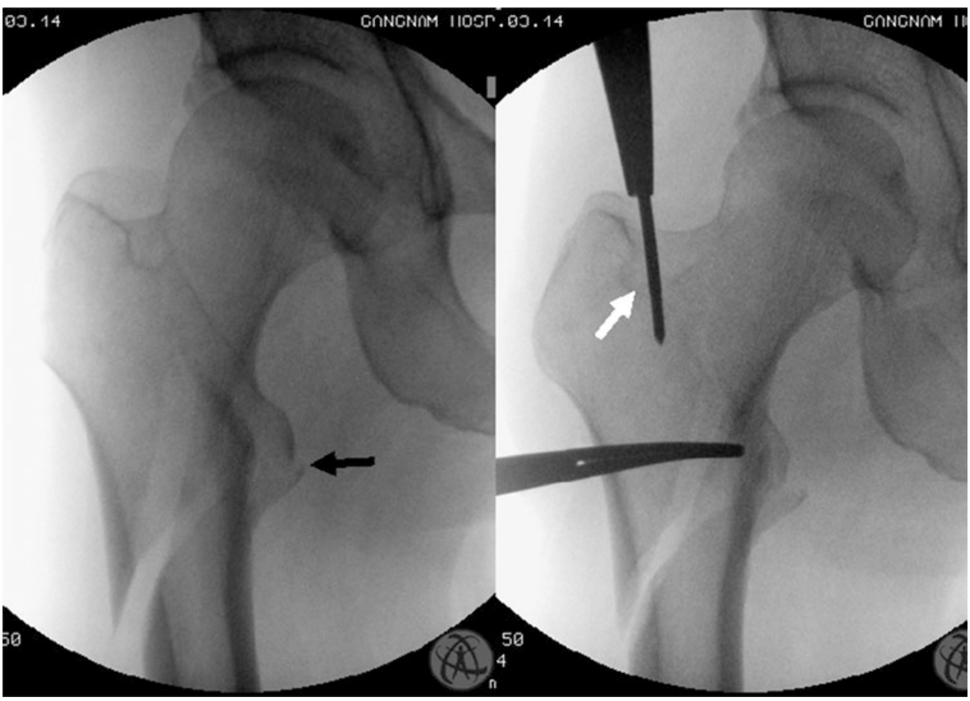

Fig. 4.8 The effects of internal rotation of the proximal fragment-I. Prominent lesser trochanter (black arrow) indicates external rotation of the proximal fragment. It shortens the femoral neck in the hip AP image and hides the trochanteric fossa by the posterior lip (intertrochanteric crest) of the greater trochanter. Internal rotation of the proximal fragment solves all the problems described in the previous sentence. The long femoral neck helps get a better orientation of the anatomic structures. An unobstructed clear view of the medial aspect of the greater trochanter opens the route to the trochanteric fossa (white arrow) for the guide pin. It facilitates the preparation of the entry point

improving visualization of the medial aspect of the greater trochanter, as shown in the following figures (Fig. 4.8) [8]. With the help of a curved cannulated awl or similar equipment, we can bend the tip of the guidewire smoothly to advance it into the center of the medullary canal (Fig. 4.7). Otherwise, it hits the medial cortex of the proximal femur. The unexpected beneficial effect of internal rotation of the proximal fragment is a simultaneous correction of associated flexion and abduction deformity of the proximal fragment (Figs. 4.9 and 4.10). After advancing a guidewire for 5–10 cm, check out the lateral image of whether the guidewire is located in the center of the medullary canal. After final confirmation of the guide pin position, entry site reaming can be performed with a trochanteric reamer. Some surgeons use a cannulated curved awl to enlarge the entry site to pass a ball-tip guide pin. It is crucial to *avoid the trochanter fossa* in the juvenile patient to prevent avascular necrosis of the femoral head after antegrade femoral nailing (Figs. 4.11 and 4.12).

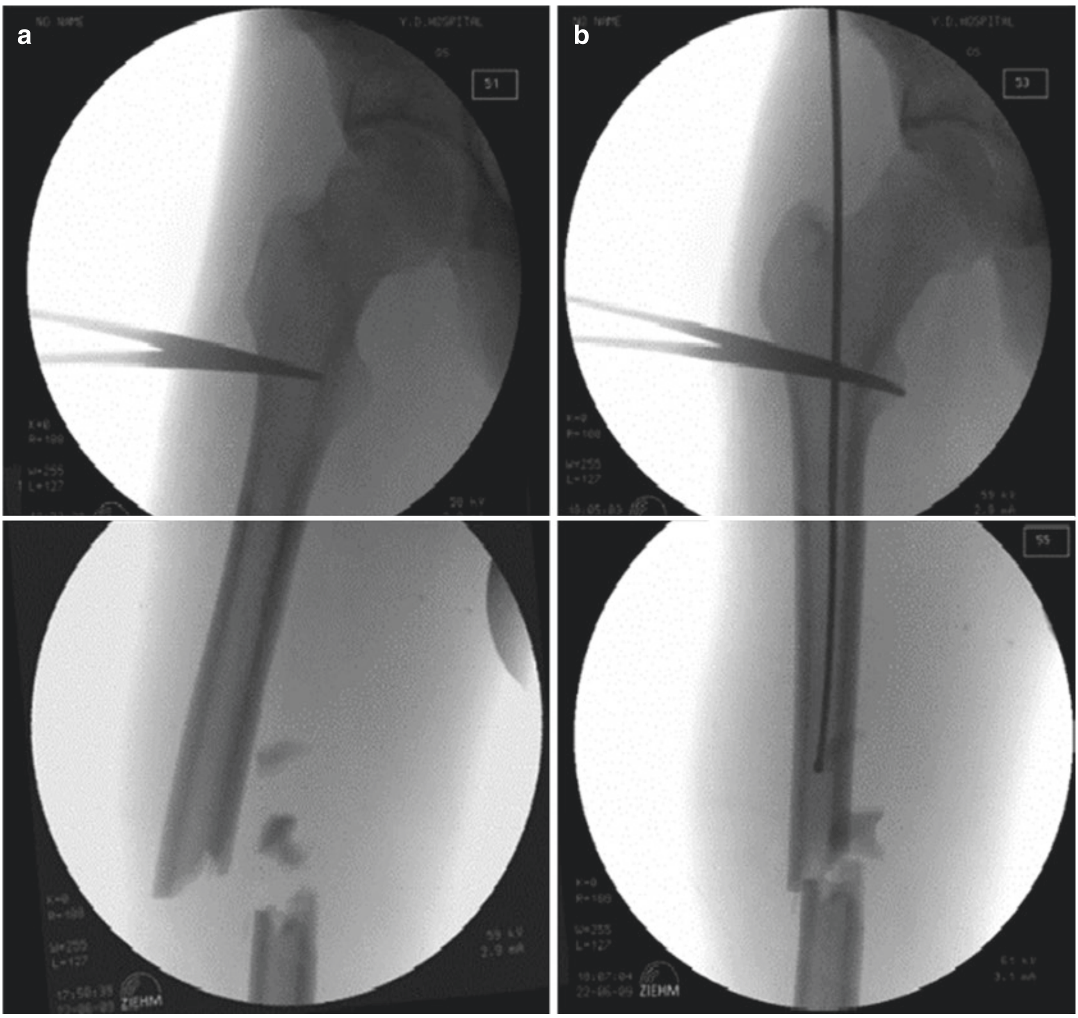

Fig. 4.9 The effects of internal rotation of the proximal fragment-II. Correction of external rotation by insertion and elevation of the curved hemostatic forceps (internal rotation) provides a clear view of the proximal femur, facilitating the preparation of the entry point. In addition, it simultaneously corrects abduction and flexion deformity of the proximal fragment and aligns the fracture fragments for easy passage of the ball-tip guidewire [9]. (**a**) external rotation of the proximal fragment. (**b**) internal rotation using the curved long hemostatic forceps

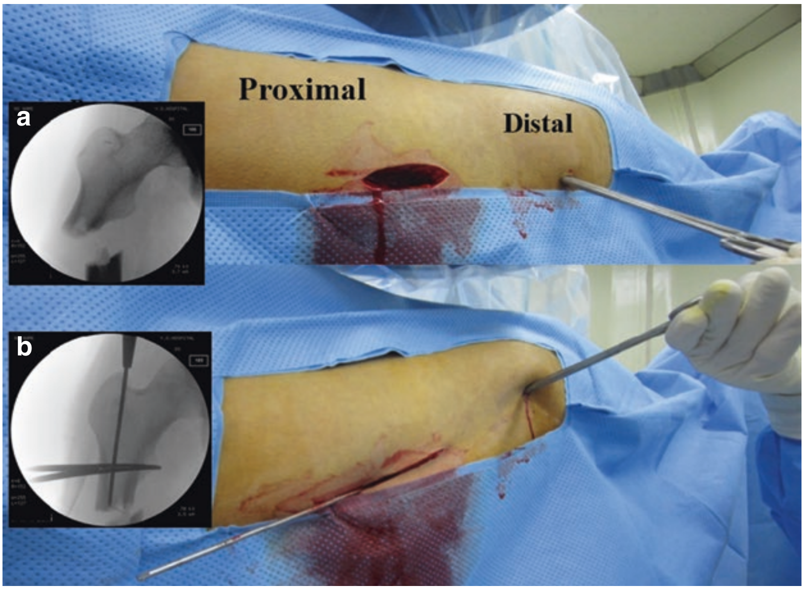

Fig. 4.10 The shorter the proximal fragment, the greater the displacement. IM nailing for subtrochanteric or proximal femoral shaft fracture is difficult due to severe flexion, abduction, and external deformity of the short proximal fragment (**a**) The shorter the proximal fragment, the greater the displacement. In general, a stab wound for insertion of the long curve hemostatic forceps is made at the lesser trochanter level. It is usually made at the posterolateral thigh (posterior margin of the femur by palpation). The arms of long curved hemostatic forceps are rolled over the lateral aspect of the femur and the anterior surface. Once it reaches the medial edge of the femur, internal rotation of the proximal femur is performed by elevating the forceps handles. It brings a clear hip AP view. It significantly facilitates the preparation of the entry site (**b**) When correction of the initial deformity is insufficient, the second forceps can be introduced and repeated [9]

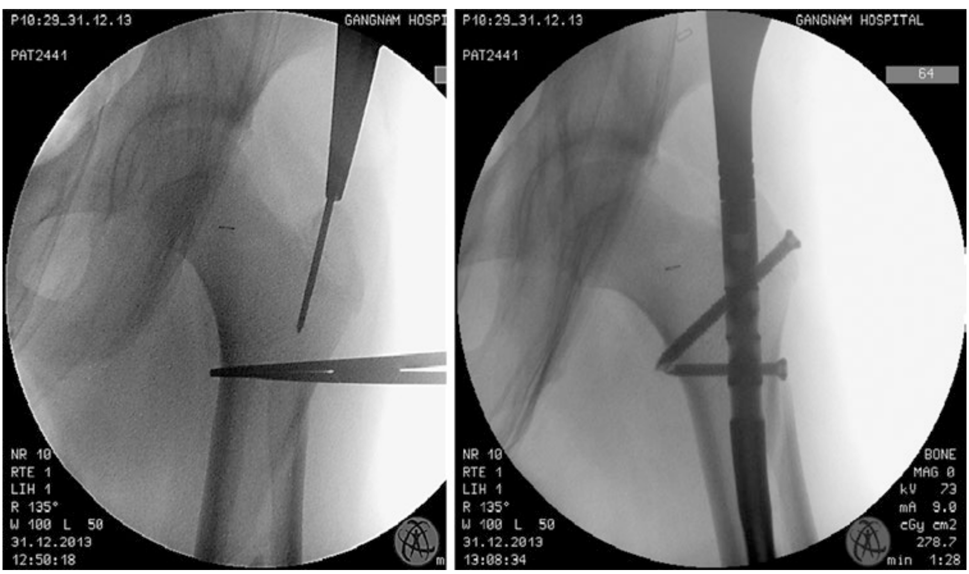

Fig. 4.11 Greater trochanter entry point for juvenile patient. A 14-year-old boy sustained a pedestrian injury. The tip of the greater trochanter was used for nail entry (ZNN greater trochanter starting antegrade femoral nail) to protect the circulation to the femoral head. It is crucial to *avoid the trochanter fossa* in the juvenile patient to prevent avascular necrosis of the femoral head after antegrade femoral nailing

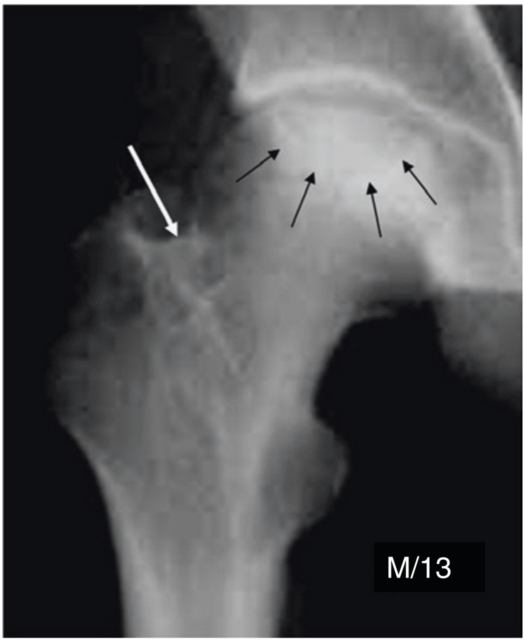

Fig. 4.12 Avascular necrosis of the femoral head after IM nailing in a 13-year-old boy. The nail entry is medial to the tip of the greater trochanter (white arrow) and avascular necrosis of the femoral head has developed at the weight-bearing area (small back arrows). This complication must be avoided

Summary of Entry Point (Fig. 4.13)
Prominent lesser trochanter (black arrow) shown in the hip AP images indicates the external rotation of the proximal fragment. Internal rotation of the proximal fragment provides clear anatomic landmarks in the superior border of the femur, such as the superior cortex of the femoral neck, trochanteric fossa (white arrow), and medial slope of the greater trochanter. Those structures are essential in selecting an appropriate entry point. The position of the guide pin must be checked in the lateral view and the AP view. After insertion of the femoral nail and interlocking screws, confirmation of the femoral neck in the internal rotation is again essential to check the possibility of an occult ipsilateral femoral neck fracture. The prophylactic femoral head and neck screw is inserted due to the "positive CT capsular sign" (see Chap. 5) in this case. Correct entry point leads to successful IM nailing. *So, do not hesitate to spend valuable time making a correct entry site even though you might experience a few unsuccessful attempts.*

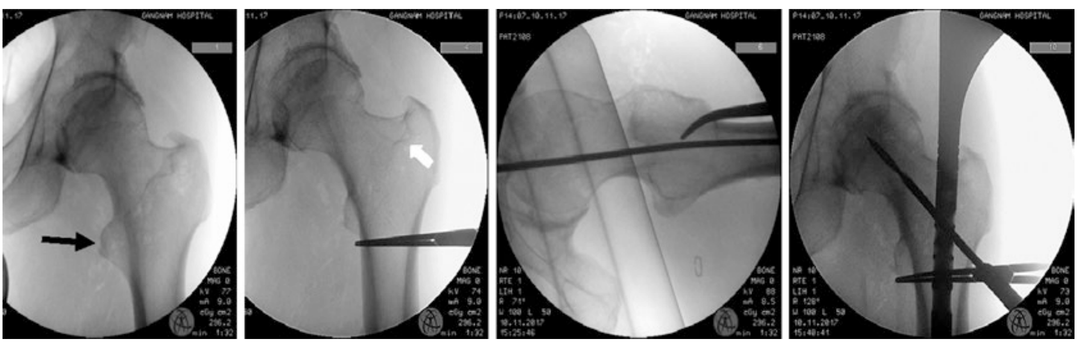

Fig. 4.13 Correct sequences for entry point preparation

4.3 Reduction Technique

Fracture reduction for IM nailing means restoration of the anatomic alignment of the femur. It consists with:

(a) Restoration of length,
(b) Reduction of the fragments for passage of a ball-tip guidewire,
(c) Correction of angulation and displacement during nail insertion,
(d) Prevention of malrotation.

(a) *Restoration of length* is usually achieved by longitudinal traction of the injured limb on the fracture table. Some surgeons performed femoral nailing in a supine position on the ordinary table. There is no problem with the cases with simple or less comminuted femoral shaft fractures. However, the fatigue limit of the assistant may hinder the precise positioning of a nail, blocking screws, and interlocking procedure in highly comminuted fractures. A simple length measure of the intact side femur from the greater trochanter to the upper pole of the patella is helpful before positioning the patient on the fracture table. In the case of both femora fractures, try to perform the less comminuted side first and use the nail of the same length on the more comminuted side [1, 10, 11]. I prefer a combination technique with an external fixator (two-staged operation) in open fracture with loss of large segment (Fig. 4.14).

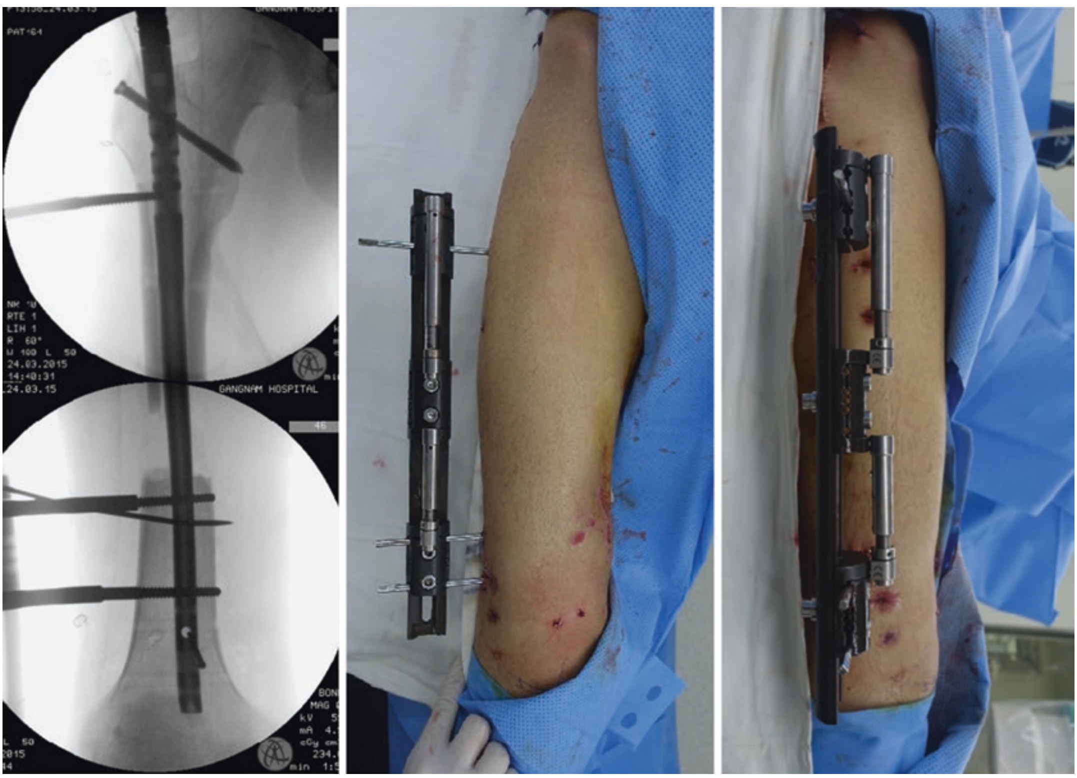

Fig. 4.14 Combination of IM nail and external fixator (EF) for lengthening in the open femoral fracture. The margin of error is tiny if you plan femoral lengthening using a Monorail type EF after femoral nailing. So precise fracture alignment, nail position (use of Poller screw to get proper alignment—lateral Steinman pin in the lower left fluoroscopic image), and correct EF pin placement are mandatory. EF pins must be perpendicular to the long axis of the femur. The proximal EF pin is through the dynamic hole of the nail, and distal EF pins are located posterior to the nail in this case. Careful preoperative planning is necessary for complicated cases. Make sure that fluoroscopy can visualize the entire length of the femur without obstruction before the surgery. For details, see Chap. 7

(b) *Reduction of the fragments for passage of a ball-tip guidewire.*

One of the most challenging deformities during the reduction of femoral shaft fracture is sagging at the fracture. This is caused by an inherent anterolateral bowing of the femur, the tension of the gastrocnemius muscle due to traction in knee extension, and the weight of the thigh. You will fail to pass the ball-tip guidewire if you attempt to correct it with more traction force. The best way is (Figs. 4.15 and 4.16):

(1) Ream the proximal fragment only until 12 mm,
(2) Insert the reduction finger (instrument) to the end of the proximal fragment,
(3) Face the fingertip toward the displaced distal fragment,
(4) Aggravate the deformity temporarily and manipulate the reduction finger so that the fingertip can catch the entry of the medullary in the distal fragment,
(5) Turn the reduction finger 90°–180° to correct the sagging deformity,
(6) Advance the reduction finger into the distal medullary canal for a few centimeters,
(7) Advance the ball-tip guidewire to the distal fragment.

A more displaced fracture is usually hard to get closed reduce in the segmental fracture. The introduction of a curved hemostatic forceps through a stab wound into the fracture site again helps reduce the fracture by leverage technique (Fig. 4.17). When displacement occurs in the long spiral fracture in the proximal or distal metaphysis,

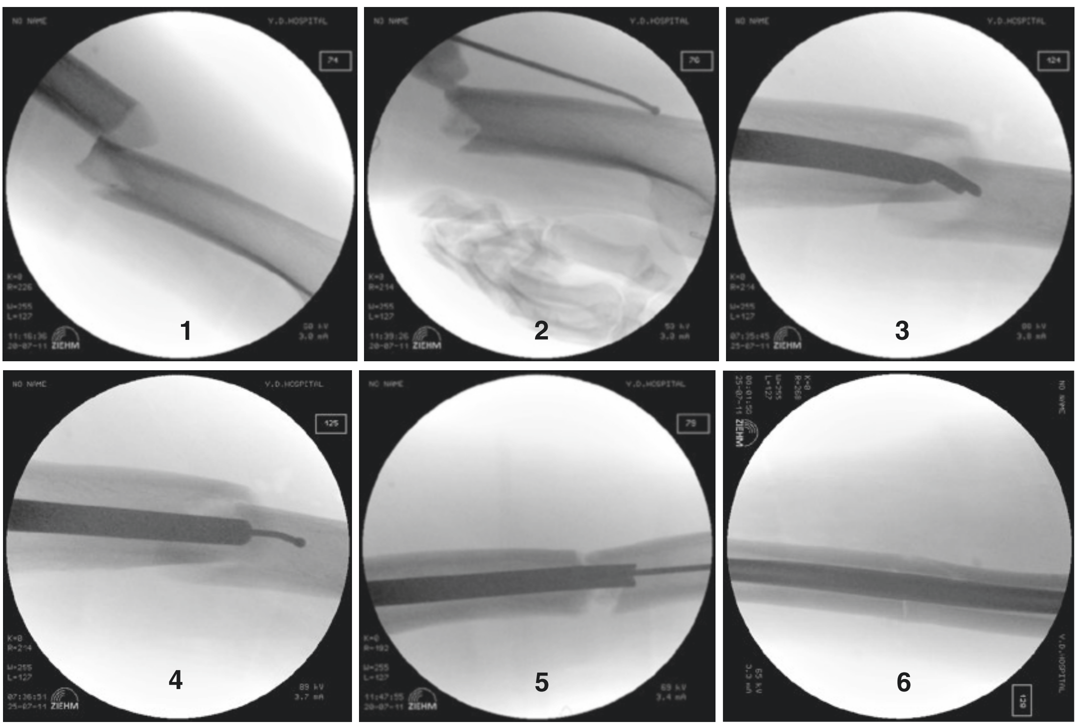

Fig. 4.15 Sagging is an annoying deformity during IM nailing. Simple external pressure or support usually fails (1, 2). You may try the crutch and band techniques when available. My favorite method is the manipulation of the reduction finger. A hard curved fingertip is advanced while searching the entry of the distal medullary canal (3). Once it enters the canal, rotation of the reduction finger reduces the fracture displacement (4–6). I used to manipulate a reduction rod or a reduction finger during IM nailing, but I think a reduction finger is a more convenient way of helping pass a ball-tip guidewire to the distal fragment. Joystick maneuver is another option

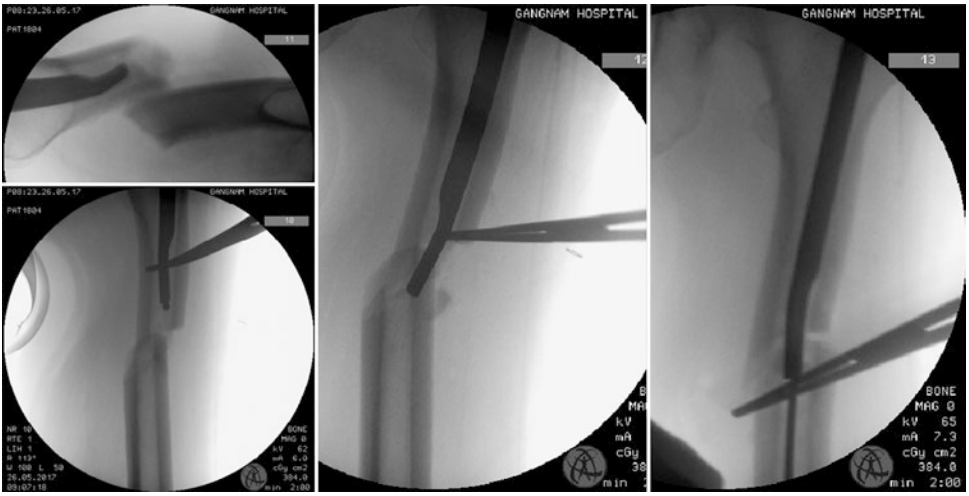

Fig. 4.16 Another demonstration of a reduction finger. Flexion deformity of the proximal fragment was controlled by the long hemostatic forceps. After reaming the proximal fragment, a cannulated reduction finger is inserted into the medullary canal with a ball-tip guidewire. The curved fingertip should face the center of the distal fragment (middle column). It facilitates catching the opening of the distal medullary canal. Serpentine movement of the reduction fingertip enables us to pass it through the medullary canal and reduce the fracture

Fig. 4.17 A segmental fracture requires the patience and skill of the surgeon. Flexion, abduction, and external rotation deformity of the short proximal fragment are corrected using the long curved hemostatic forceps [serial images on the upper column]. Distal one-third fracture shows a huge displacement. Use of reduction finger is not appropriate due to long lever arm in the distal fracture. Introduction of a curved hemostatic forceps through a stab wound into the fracture site again helps reduction of the fracture by leverage technique [scooping of the far fragment (middle fragment) using the forceps arms while the body of the forceps abuts the near fragment (distal fragment) working as a hinge (thick white arrow indicates reduction maneuver)]. Once the shortening and displacement were overcome, the reduction would be achieved with a clunk (thin white arrow) [serial images on the lower column]

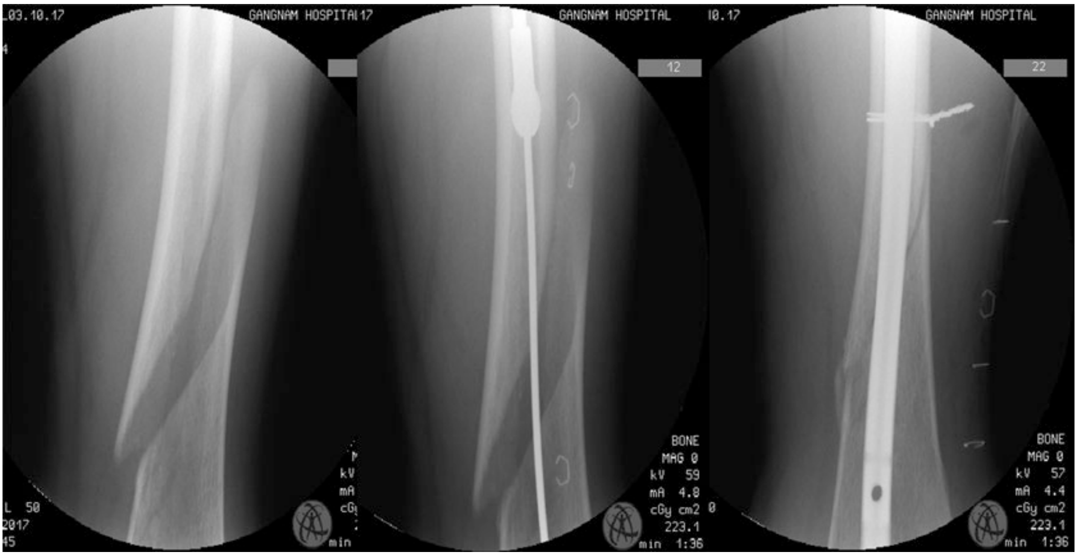

Fig. 4.18 Long spiral fracture at the distal one-third of the femur is a good indication of wiring. Since the fracture usually occurs in the old ladies, it is difficult to be reduced by Poller screw alone. Application of Poller screw without initial reduction may cause second fracture (split of the distal fragment) due to osteoporosis. The wiring technique effectively reduces the fracture gap and augments the fixation with the interlocking nail. As there have been reports of entrapment of a femoral artery and subsequent above-knee amputation after wiring, it must be performed with special care. Wire passer must be touched with the femur through the course and procedure [12]

wiring the fracture after the open or semi-open technique is preferable to leaving a large gap. Cerclage wiring of the displaced fracture with minimal soft tissue handling gets popular these days. It helps reduce the long spiral fracture or large butterfly fragment and enhances stability during and after nailing (Figs. 4.18, 4.19, and 4.20).

(c) *Correction of angulation and displacement* is less problematic in the shaft area than in the infra-isthmic area because occupancy of the medullary canal with the largest nail possible after adequate reaming automatically realigns the diaphysis unless the isthmic area is highly comminuted. However, in the distal metaphyseal area, the medullary canal widens like the bell of a trumpet, negating the effect of the IM nail. Use of Poller screw or blocking screw is highly advocated in this area when angulation of the distal fragment hinders the restoration of anatomical alignment. Advantages of Poller screw are enhancement of distal fixation by preventing recurrence of angular displacement as well as correction of angular malalignment during nail insertion (Figs. 4.21 and 4.22) [1, 11, 13].

Displacement frequently occurs in the distal femoral fracture. The use of various bone clamps is necessary to get the reduction. Ugly displacement at the supracondylar area is challenging to be reduced by ordinary methods. A Schanz pin at the lateral femoral condyle for manipulation, a Poller screw on the nail's lateral side, and a collinear clamp are useful tools for closed reduction (Fig. 4.23).

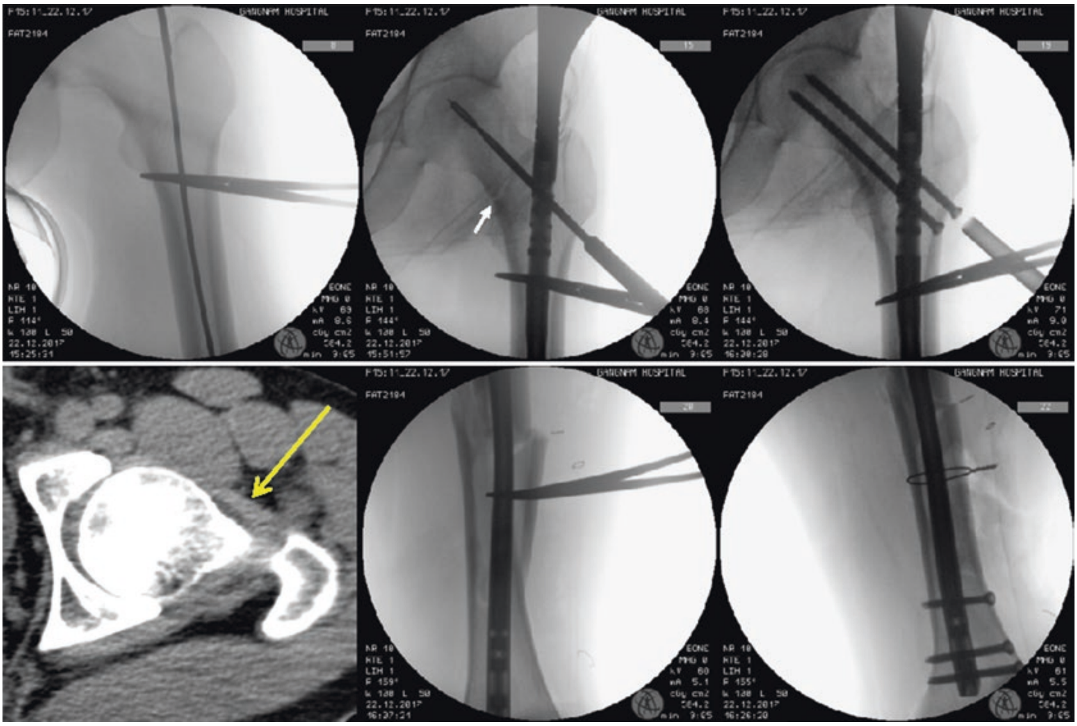

Fig. 4.19 Wiring of the comminuted fragment needs small incision usually at the lateral aspect of thigh. Initial valgus malalignment was corrected after wiring of the comminuted fragment. In this case, undisplaced silent ipsilateral femoral neck fracture was displaced during the nailing (small white arrow). Therefore, reconstruction type nailing was performed. Preoperative hip axial CT images revealed capsular sign that implicated undisplaced femoral neck fracture (see Chap. 5)

(d) *Rotational alignment*. Once length and correction of the angular deformity are achieved, it is time to think of the rotational status of the nailed femur. Anteversion of the femur is different from person to person (Fig. 4.24). In general, restoration of rotational alignment between 0° and 15° is advocated unless the angle of anteversion is measured by computed tomography in the contralateral femur beforehand. Malrotation over 15° is not recommended. The lesser trochanteric sign is extremely valuable, but the surgeons frequently focus on IM nailing procedure itself and omit to get the AP image of the contralateral hip with the patella forward beforehand (Figs. 4.25 and 4.26) [11, 14–17]. Taking advantage of an inherent anteversion of the intramedullary nail is a useful tip to avoid the malrotation in the highly comminuted femur fractures, which includes fracture of the lesser trochanter (Fig. 4.27) (Table 4.1).

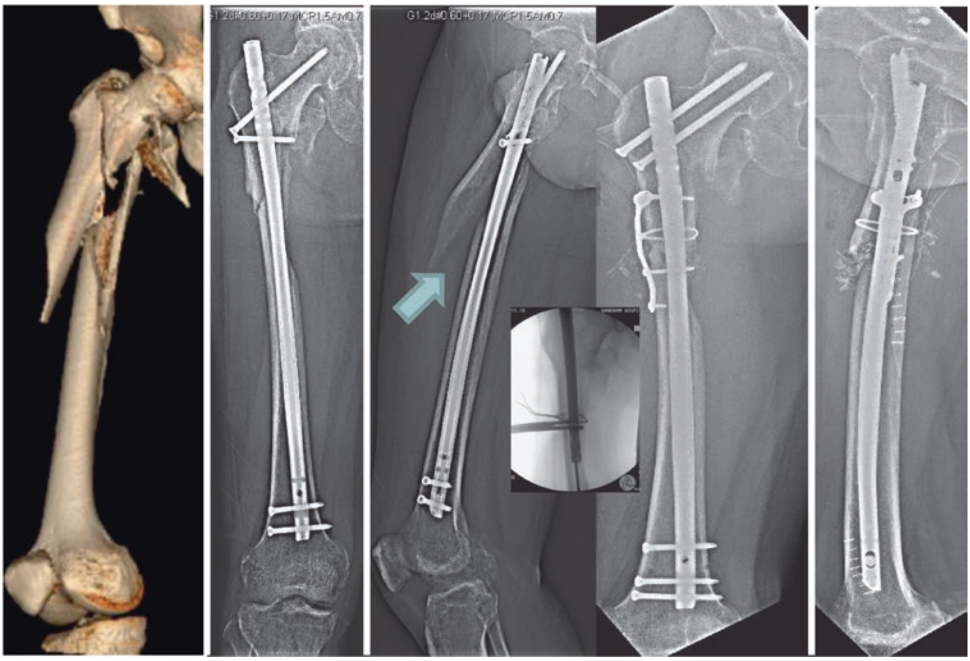

Fig. 4.20 A 35-year-old male patient sustained a motorcycle accident. He underwent closed reduction and internal fixation with a reconstruction nail for the trochanteric fracture with serious subtrochanteric extension. However, the surgeon failed to get a proper reduction (arrow). Six months after the initial surgery, he was transferred to our hospital for revision. Due to a long-standing malalignment, open reduction using a bone clamp and cerclage wiring was necessary to maintain the reduction during exchange nailing. Plate augmentation and autoiliac bone graft were performed due to the gap at the fracture site. Due to the fracture of the lesser trochanter, the inherent anteversion of the ZNN femoral nail (15°) was used to get proper rotational alignment (see below). Proper alignment was achieved and bone healing was progressing 2 months postoperatively. Flexion deformity of the proximal fragment was corrected as shown in the lateral view of the femur after the operation (right). A bone clamp and cerclage wiring were applied to reduce the gap during IM nailing. Augmentative plating and autoiliac bone graft were performed due to a defect on the medial side

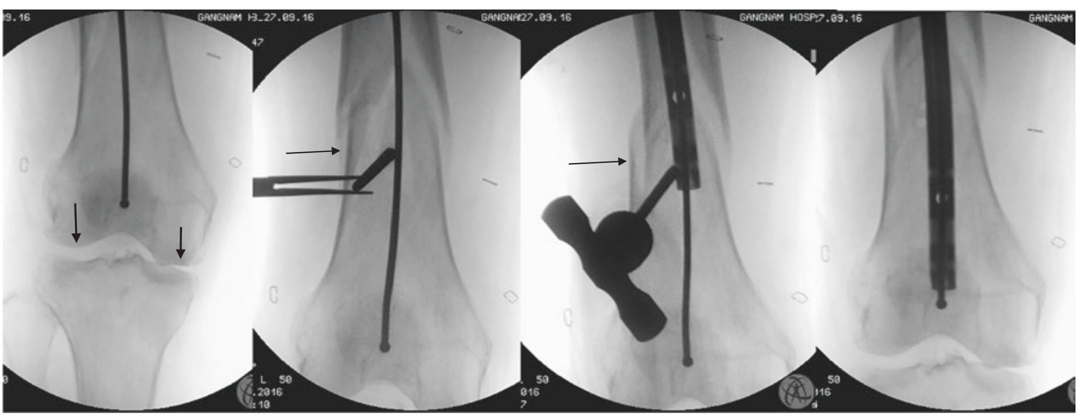

Fig. 4.21 Poller screw (pin) to realign the distal fragment. Although a longitudinal alignment looks good after reduction, flattening of the medial femoral condyle and valgus of the femoral articular surface are noted (arrows in the left image). A Steinmann pin is inserted just lateral to the ball-tip guidewire to induce lateral displacement of the distal femur and decrease the valgus alignment (compare each arrow in the two middle fluoroscopic images). The lateral cortex of the distal fragment moves laterally when the nail abuts the Poller pin. (See Chap. 8 for the use of a Poller pin for the subtrochanteric fracture)

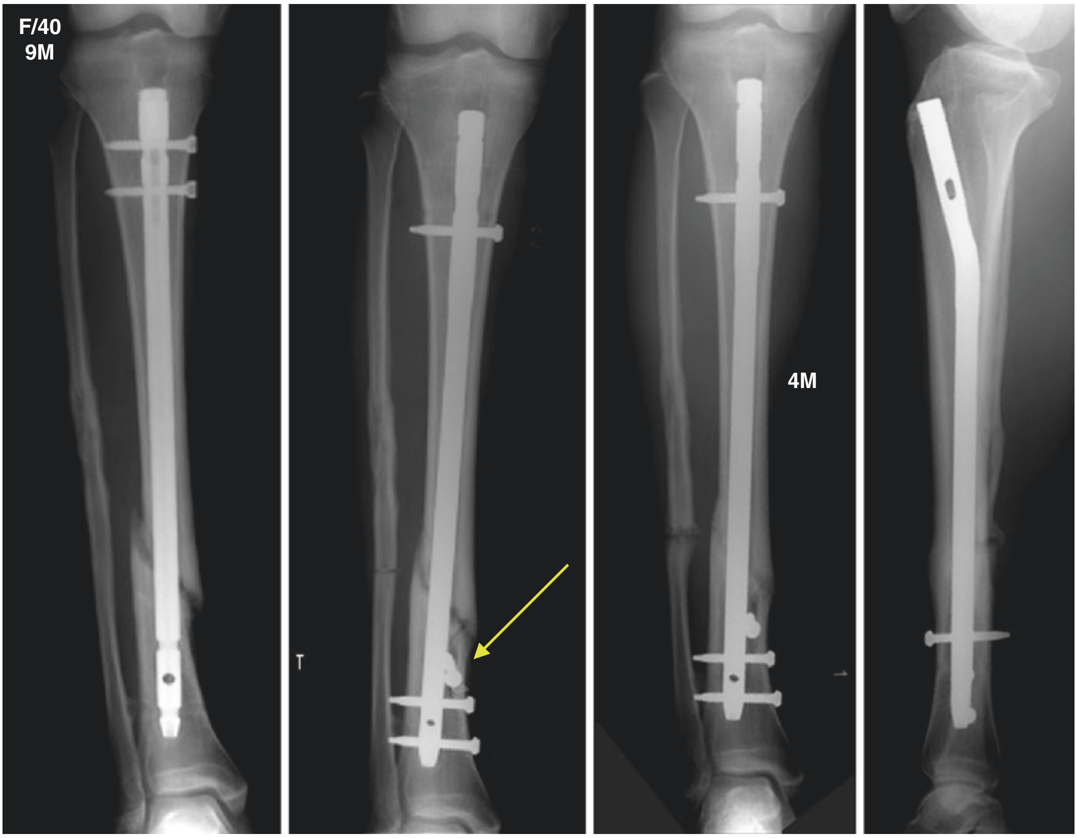

Fig. 4.22 Correction of malalignment and nonunion by exchange nailing technique with a Poller screw. A 9-month-old nonunion with malalignment is difficult to treat with a simple exchange nailing technique alone. An osteotome of the fibula and a Poller screw insertion was necessary to correct the varus malalignment and a lateral displacement of the distal tibial fragment. A Poller screw (long arrow) was inserted on the concave side of the distal fragment before the insertion of a new nail. Varus deformity was corrected and nonunion healed in 4 months

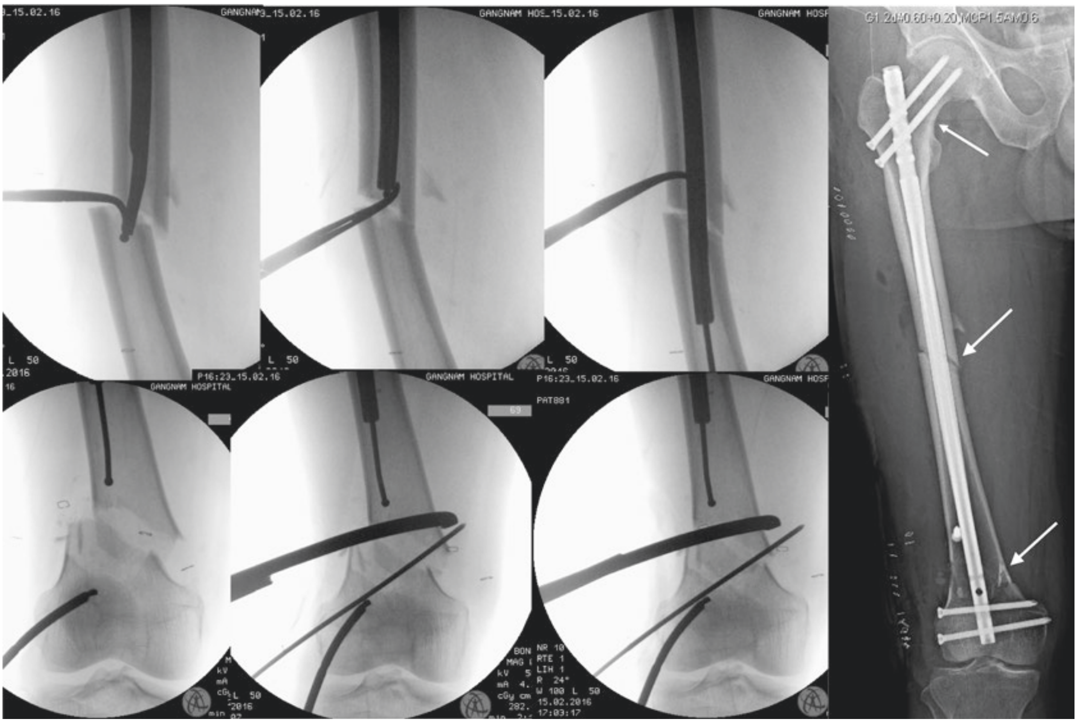

Fig. 4.23 Problems in segmental fracture. One of the biggest problems in the segmental fracture is difficulties in getting adequate traction. Due to insufficient traction, a reduction finger was unable to pass through the distal medullary canal. With the help of the hemostatic forceps leverage technique, (Fig. 4.17), length was restored, and passage of the reduction finger was permitted (upper left column). Ugly displacement at the supracondylar area was impossible to be reduced by the ordinary method. A collinear clamp was used to approximate the fragments gradually, and they were fixed with a temporary pin. A Schanz pin was inserted at the lateral femoral condyle for manipulation (lower left column). A Poller screw was inserted on the lateral side of the nail in the middle fragment to keep the nail in the center of the medullary canal. Proximal interlocking screws were inserted into the femoral head and neck due to undisplaced ipsilateral femoral neck fracture (a white arrow in the femoral neck). Injury around the knee joint (for example, posterior cruciate ligament avulsion fracture, patellar fracture, supracondylar fracture of the femur) is a risk factor of occult ipsilateral femoral neck fracture (right image, see Chap. 5)

Fig. 4.24 Correct method of measuring femoral anteversion. Dried femora are placed on the table as shown in the upper column. The posterior aspect of both femoral condyles must touch the table surface. Then, the pictures are taken from the proximal aspect. The inclination angle of the femoral neck and head is an anteversion of each femur by definition. The anteversion of the left side femur is 15° and the right one 0°

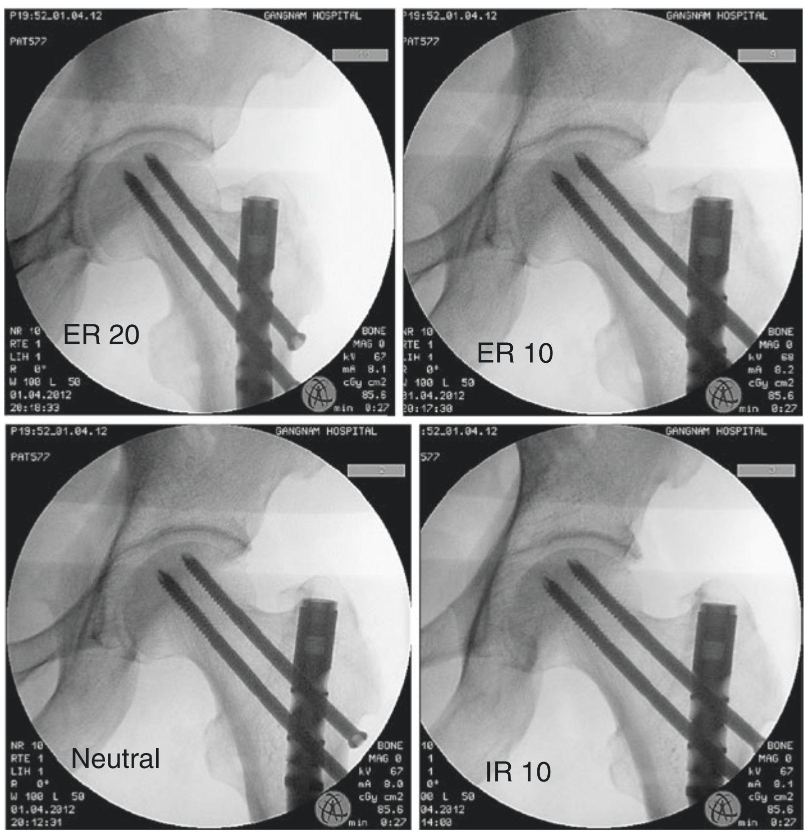

Fig. 4.25 The shapes of lesser trochanter in the hip AP view in the various angles of hip rotation. The lesser trochanter is prominent when the proximal femur is rotated externally. *If the hip AP is taken with the patella forward, it implicates that the fractured femur is fixed in internal rotation*

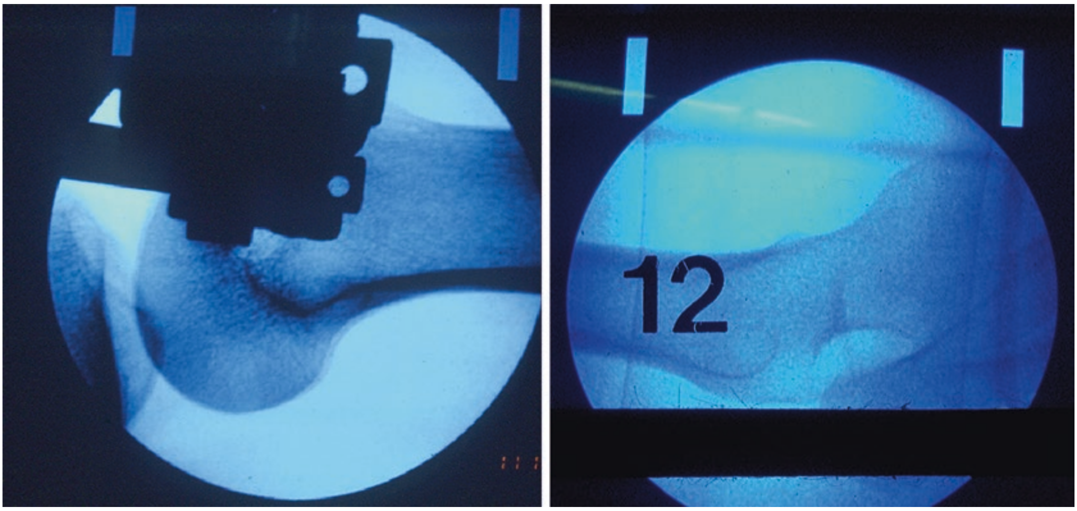

Fig. 4.26 Intraoperative measurement of femoral anteversion. By definition, the inclination of the femoral neck and head is anteversion if the posterior aspects of both femoral condyles overlap in the horizontal beam of the fluoroscopy. This technique is useful in the case of severely comminuted femoral shaft fracture, as shown in the preface of this book. Modern femoral nail (for example, ZNN antegrade femoral nail) is manufactured with 15° of anteversion. So, if the femoral neck and head screw are positioned in the center in the lateral view and the circular distal interlocking hole is visible with overlapping of the posterior aspects of both femoral condyles, the femur has anteversion of 15° (see the case figure below)

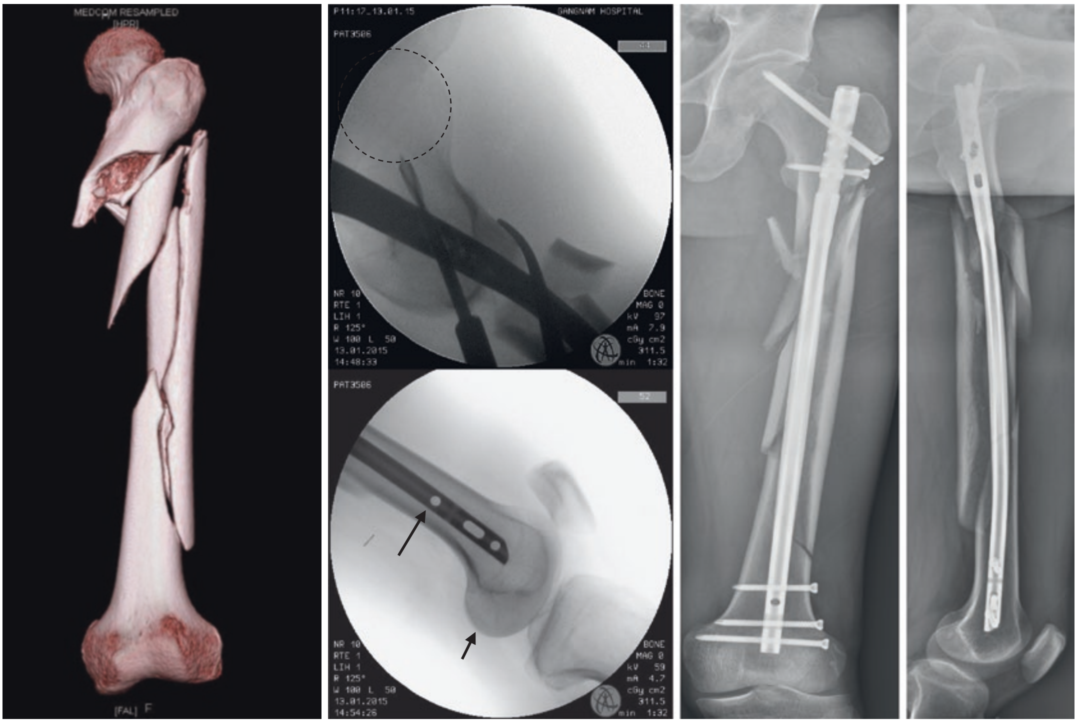

Fig. 4.27 Technique of using an inherent anteversion of intramedullary nail to avoid the malrotation in the highly comminuted femur fractures. Proximal femoral neck and head screw must be located at the center in the lateral view (middle column, upper image). In the distal part of the femur, the fluoroscopy must be manipulated to get a circular distal interlocking hole (long black arrow). Then, rotate the distal femoral fragment by rotation of the footplate or skeletal traction device to overlap the posterior aspect of both femoral condyles (short black arrow in the lower image, middle column). Holding the targeting guide connected to the nail facilitates correction of malrotation deformity while the assistant rotates the distal leg. Insert the distal interlocking screws accordingly. The femoral anteversion matches that of the nail inserted (In this case, the anteversion of ZNN femoral nail is 15°). This technique is beneficial when the shaft fracture is associated with the lesser trochanteric fracture

Table 4.1 Inherent anteversion of the reconstruction nails [15, 18–21]

Brand name	Company	Anteversion (degrees)
T2	Stryker	10
Trigen	Smith & nephew	12
FRN	DePuy Synthes	14
ZNN	Zimmer-Biomet	15

4.4 Reaming of the Medullary Canal

The Küntscher nail was inserted into the medullary canal after the medullary reaming. The purpose of medullary reaming is to insert a large diameter nail which provides more nail strength and more significant contact areas with the femoral shaft. However, medullary reaming violates medullary circulation. In addition, the inadequate reaming procedure may cause excessive embolism of medullary contents and heat necrosis. In that context, unreamed IM nails were popular in the late twentieth century due to shorter operation times and minimally invasive procedures. However, after reamed IM nailing, overall results are better than those of unreamed ones. Thus, insertion of a reamed interlocked femoral nail after minimal cortical reaming has become the major trend in femoral nailing [7, 8, 11, 22–24]. After successfully positioning the ball-tip guidewire into the center of the femoral

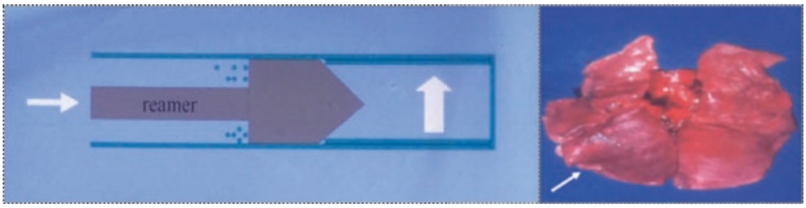

Fig. 4.28 Pulmonary embolism of the medullary contents in forceful reaming. The reamer head acts like a piston within a syringe. So, the IM pressure in the distal medullary cavity (large white arrow on the left image) may increase if the reamer head advances fast (small white arrow). The green droplets indicate cortical reaming debris expelled behind the reamed head. Rapid advancement may cause pulmonary embolism of the medullary contents, as shown in the lung of the canine fracture model. Congestion in the right lower lobe (small white arrow on the right image) is caused by pulmonary embolism after rapid cortical reaming

condyle through the medullary canal, the reaming process can be started from 7 mm (diameter of the reamer head) end-cutting reamer. Then the reamer size can be increased by 1 mm until it touches the endocortex (the inside layer of the cortex). I prefer an additional 0.5–1.0 mm increment in reaming for proper contact between the nail and endocortex. The edges of the reamer head must be sharp and rotate fast. It must be advanced slowly within the medullary canal to prevent heat necrosis and embolism of medullary contents. Use of ball-tip guidewire is mandatory to withdraw the broken reamer. It is also helpful in the case of reamer head jamming. In the past century, the reamer shaft was made of a spring coil, so reverse rotation (counterclockwise rotation) of the motor uncoils the reamer shaft. The modern reamer shaft is made of a hollow cylinder (stainless steel) so reverse rotation is possible when the reamer head is jammed in the medullary canal.

The IM pressure in the distal medullary cavity may increase if the reamer head advances too fast (Fig. 4.28). I prefer making a ventilating hole at the distal femoral shaft in case of subtrochanteric fracture (long distal fragment) and prophylactic femoral nailing for the incomplete atypical femoral fracture to decrease the IM pressure during the reaming process. Careless rapid reaming may cause pulmonary embolism of the medullary contents, as shown in the lung of the canine model (Fig. 4.28) [25].

The shape of the reamer head is also critical to decrease the medullary pressure. The figure shows the difference in the distance between the reamer core and the cutting edge. It must be good enough to expel the reaming debris behind (Fig. 4.29) [25, 26].

The careless reaming causes cortical heat necrosis. It seems harmless in the early postoperative period but eventually results in nonunion because of the necrotic sector in the cortical bone. Therefore, wide debridement of necrotic tissue, including cortical segment and reconstruction of the defect, is necessary (Fig. 4.30) [27–29].

The Reamer Irrigator Aspirator (RIA; Synthes) is a surgical instrumentation system that uses negative pressure to circulate fluid through the intramedullary canal during reaming of long bones (Fig. 4.31). Compared to the traditional methods of reaming, the RIA is designed to lower intramedullary pressure and temperature in order to reduce the incidence of fat embolization and thermal necrosis. The RIA system is also commonly used to collect autologous bone grafts as an alternative to iliac crest bone graft [30, 31].

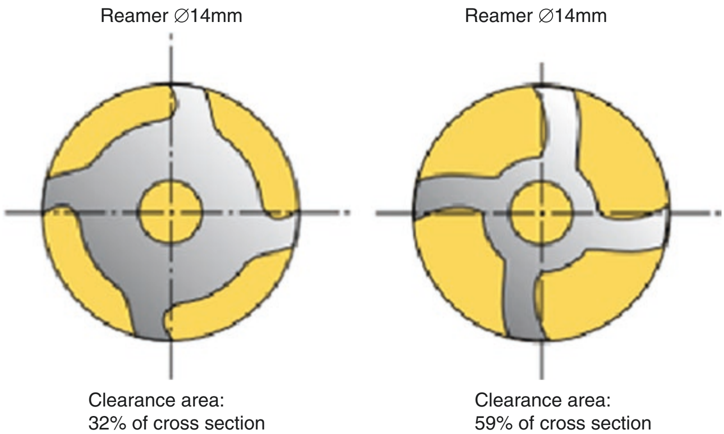

Fig. 4.29 Reamer head. The difference in the distance between the reamer core and the cutting edge is shown. The distance must be good enough to expel the reaming debris behind, namely the clearance area. Compare the clearance areas between the two reamer heads, which determine IM pressure during reaming process. For example, the right Bixcut reamer increased the clearance area by more than 80% in 14 mm reamer head compared to that of the conventional reamer (Stryker, Bixter reamer system) [26]

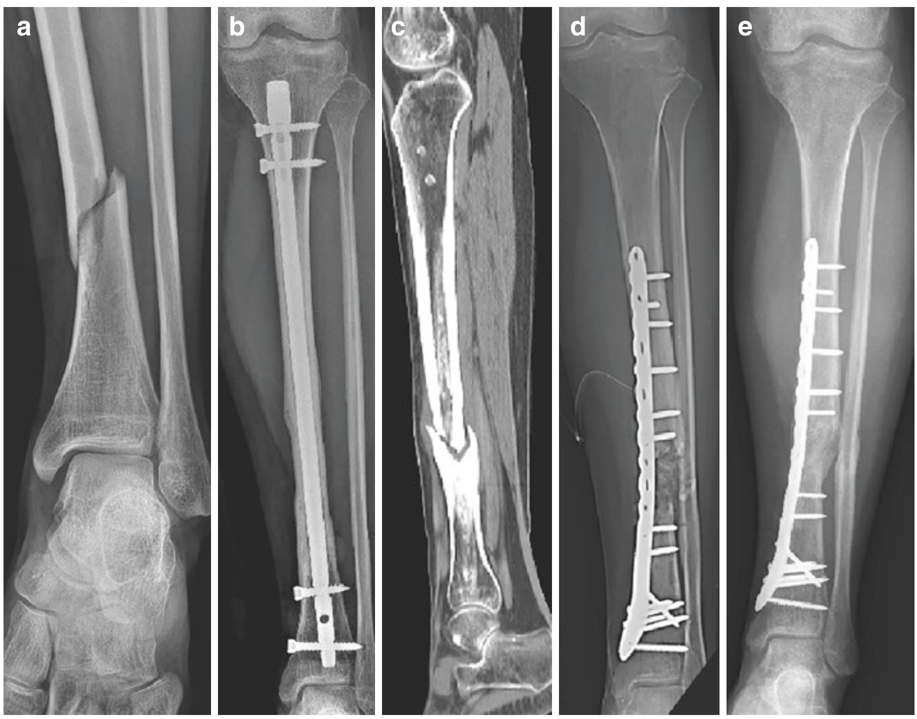

Fig. 4.30 Heat necrosis of the cortex after reaming in the narrow medullary canal. A 23-year-old lady sustained a short spiral fracture at the distal tibia after slipping down (**a**). She underwent closed reduction and internal fixation with a reamed interlocked tibial nail. One year after the operation, the fracture seemed to get united with the periosteal callus, and the IM nail was removed. However, thinning of the diaphyseal cortex suggests excessive cortical reaming due to the narrow medullary canal (**b**). One year after the removal of the nail, the CT image shows nonunion due to failure in remodeling around the fracture site (**c**). The nonunion site was necrotic in the segment, so wide debridement was necessary. Autoiliac bone graft and plate osteosynthesis with a locking plate were performed (**d**). One and a half years after the reconstruction surgery, the bone defect was healed (**e**)

Fig. 4.31 Reamer Irrigator Aspirator (RIA) system. Upper right image: reamer head with ball-tip guidewire inside, lower right image: harvested autogenous bone [30, 31]

IM nailing is the optimal solution in specific metabolic bone diseases. It can be performed in some cases of autosomal dominant type II (AD II) osteopetrosis with special care on reaming. In AD II osteopetrosis, the medullary canal is extraordinarily narrow and obliterated in some segments. Therefore, it needs careful preoperative planning and slow but steady procedures confirming safety step by step. Evaluation of the medullary canal size using CT axial views is mandatory. Since reaming of hard cortical bone is necessary, slow reamer advancement with high RPM (revolutions per minute) is crucial. See Chap. 11 for details (Fig. 4.32) [32].

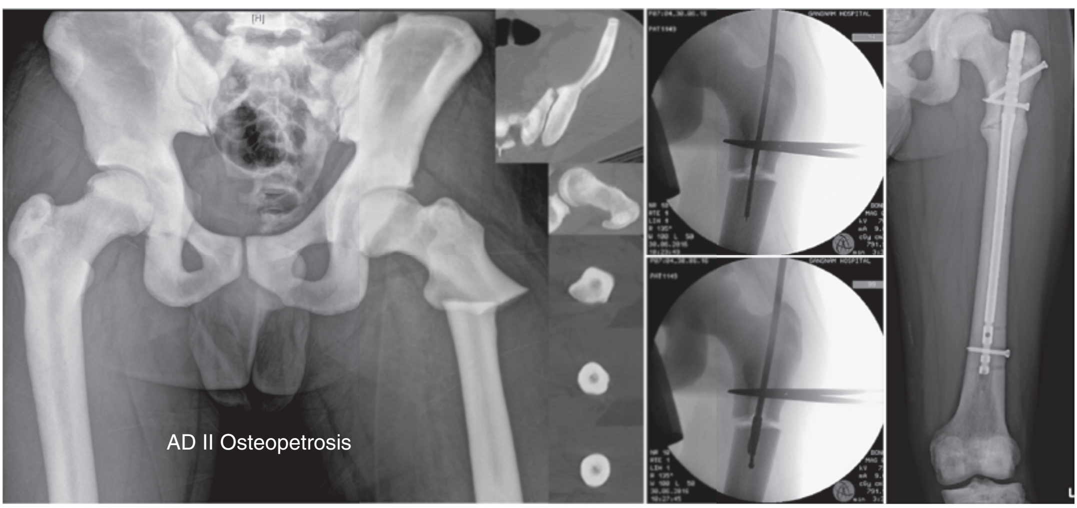

Fig. 4.32 Medullary reaming for IM nailing in the autosomal dominant type II osteopetrosis patient (see Chap. 11). A 33-year-old male patient sustained a subtrochanteric fracture after a simple fall. Obliteration of the IM canal is evident in the serial axial CT images of the femur in this AD II osteopetrosis patient. To protect the surgical implant, we decided to fix this fracture using IM nail rather than plate because the defects in osteoclast function take several years to remodel. The main obstacle in IM nailing was the obliteration of the medullary canal. The entry site and medullary canal were searched and prepared with a 4.9 mm long drill bit for 6 mm screw for reconstruction nail. Once the drill advanced a few centimeters, I replaced it with a ball-tip guidewire and reamed the canal sequentially with 0.5 mm of increment. Since the ball-tip guidewire cannot penetrate the medullary cavity, a long drill was used in every step to open the canal for a few centimeters. Callus formation and healing are evident after IM nailing [32]

4.5 Insertion of the Femoral Nail

After adequate reaming of the medullary canal, the femoral nail can be advanced without difficulties. A loud hammering sound indicates that something is wrong. Smooth advancement of the nail by each blow of a hammer is essential. In case of excessive femoral bowing, it is necessary to rotate the femoral nail externally while it passes the curve's apex (see Chap. 8) [33]. In a long oblique or spiral fracture at the isthmus, the flexible reamers move like snakes in the fracture zone, missing one cortex. Unreamed portion in the inner cortex (bump) also causes bursting of the cortex (Fig. 4.33).

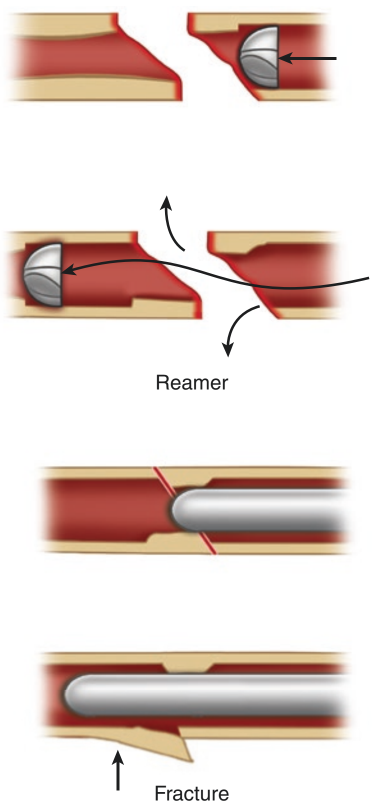

Fig. 4.33 Bypass of the reamer and ineffective reaming in the long oblique fracture. The reamer heads lose contact with the cortex within the fracture zone in case of long oblique or spiral fractures around the isthmus. Once the advancing nail reduces the fracture, the unreamed cortex interferes with the advancement of a nail or causes a fracture eventually. It may not be a significant complication in interlocked IM nailing, but it is advisable to expect it and explain it to the patient before the surgery

Hard endosteal callus in case of atypical femoral fracture after long-term bisphosphonate intake may also cause jamming or bursting of the cortex. Therefore, it is sometimes necessary to remove it using a long narrow chisel to widen the medullary canal (Fig. 4.34). Otherwise, it may also cause bursting of the femoral cortex during the hard insertion of a femoral nail [33–35].

If the fracture locates in the distal part of the femoral shaft, the nail tip must be placed in the femoral condyle for distal interlocking. How deeply can the nail be inserted? The nail tip can be advanced until it touches the V-shaped corner, which is made by the upper intercondylar articular and the lower Blumensaat lines. An undisplaced intercondylar fracture, usually an extension of the primary distal femoral fracture, can be fixed with one or two lag screws before femoral nailing (Fig. 4.35).

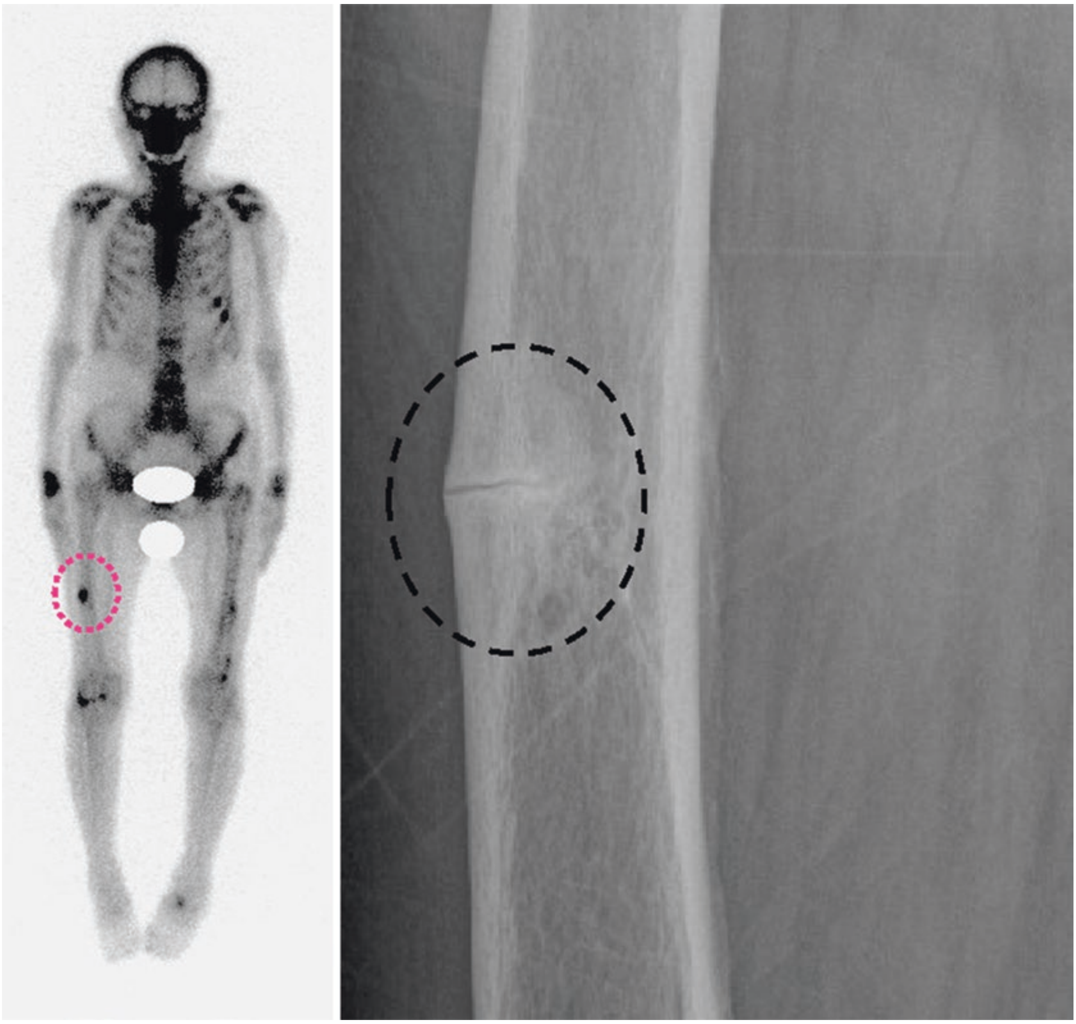

Fig. 4.34 Hard endosteal callus that interferes with the medullary reaming. An 80-year-old lady sustained left atypical femoral shaft fracture and right Colles' fracture and was treated by IM nailing and plating, respectively. Tc^{99m} bone scan shows multiple rib fracture and impending atypical femoral fracture on the right femoral shaft (small circle). Due to the propagation of a lateral crack to the midline of the femoral axis, prophylactic nailing is indicated. Hard endosteal callus and sclerotic fracture margin interfere with the passage of a ball-tip guidewire and reamer (large circle). Opening the medullary canal was necessary using a 4.9 mm long drill bit. The introduction of a ball-tip guidewire was possible, and slow sequential reaming with end and side cutting reamers were necessary for IM nailing

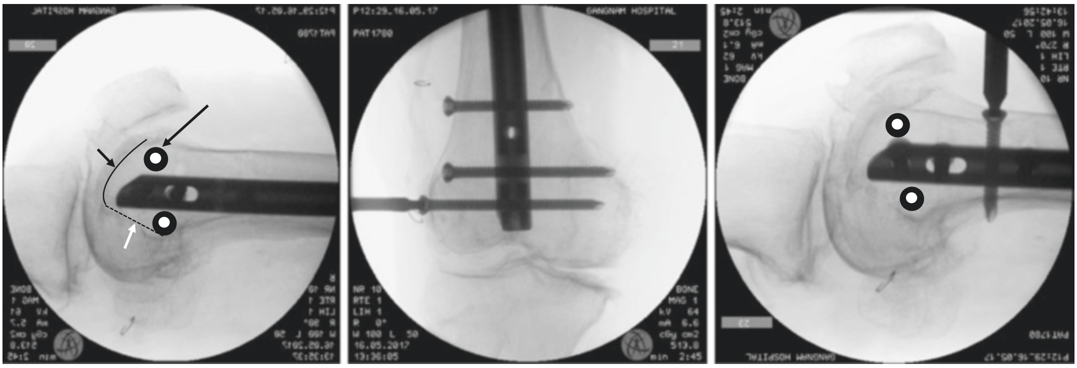

Fig. 4.35 Intraoperative fluoroscopic images depict the position of the nail tip, distal interlocking screws, and lag screws (long black arrow). The nail tip can be advanced until it touches the V-shaped corner made by the upper intercondylar articular (small black arrow) and the lower Blumensaat (white arrow) lines. An undisplaced intercondylar fracture can be fixed with the cannulated lag screws (long black arrow) before femoral nailing

4.6 Mode of Interlocking

In the late twentieth century, most nails were equipped with static round holes alone; therefore, removing all interlocking screws from one main fragment was inevitable to achieve the dynamization effect. Advocates for routine dynamization believed that load-bearing on the fracture callus promoted fracture healing and rehabilitation of patients. However, Brumbeck et al. reported that most fractures were healed when treated with the static mode; thus, routine dynamization was not indicated. Moreover, the dynamic unlocking mode sometimes resulted in angular instability and excessive shortening due to displacement of the undetected fracture line in 10% of patients. Therefore, the static mode became the standard method of interlocking fixation in femoral nailing [4, 23, 36].

Modern femoral nail systems usually provide dual options for interlocking fixation, namely dynamic and static modes, in both the distal and proximal portions. There is one dynamic hole in each proximal and distal portion. The dynamic mode is subclassified into unlocking (no interlocking screw fixation) and dynamic locking (interlocking screw fixation at the dynamic hole only) modes. The static mode is subclassified into static locking (interlocking screw fixation at the static hole only) and hybrid locking (interlocking screw fixation at both the dynamic and static holes) modes. In the status of hybrid locking mode, conversion to the dynamic locking mode (dynamization) can be achieved easily by removing the static interlocking screws located beside the dynamic interlocking screw. *Do not forget to remove the ball-tip guidewire before drilling for interlocking!*

Modern femoral nails also provide various proximal and distal interlocking options to treat associated proximal (femoral neck and trochanteric) and distal (supracondylar) fractures (Fig. 4.36). Proximal interlocking screws are usually inserted through the holes in the attached targeting guide. Please choose the best option for proximal fixation among them.

1. One of the difficulties in proximal interlocking is the correct positioning of the femoral neck and head screw (reconstruction screw). Unlike insertion of the oblique screw from the greater trochanter to the lesser trochanter, the reconstruction screw needs unique technique, especially when two reconstruction screws must be inserted. The level of the proximal interlocking holes in the nail must match with that of the femoral neck and anteversion. To insert the long reconstruction screw properly in the femoral head, the tip of the reconstruction screw must be placed at the center of the femoral head in the lateral view. We found a helpful tip for correcting a guide pin that is

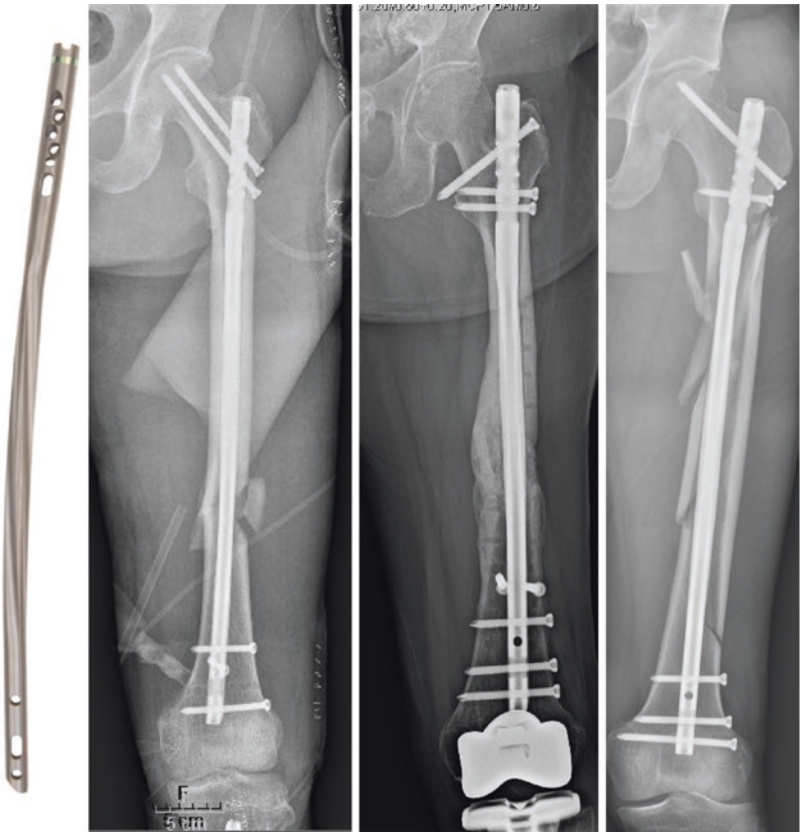

Fig. 4.36 Various patterns of the proximal and distal interlocking. Combining interlocking screws in different directions is possible in modern femoral nails. In the proximal portion, reconstruction and transverse interlocking screws can be inserted through the targeting guide according to the fracture configuration. Distal interlocking screw holes are oriented in latero-medial and anteroposterior directions. Additional stability can be obtained by inserting Poller screws beside the nail in the osteoporotic bone. Some holes are designed in oblong (or oval) shape so that dynamic interlocking is possible in femoral nailing and exchange nailing

inserted in an improper position. The movement of the guide pin in the posterior direction in the lateral view is associated with inferior migration of the guide pin in the AP view. The greater the anteversion of the femur, the more significant the shift of guide pin in AP view per degree of correction in the lateral view (Fig. 4.37) [37].

2. Skidding the guidewire frequently happens, especially in young patients. Principal compression trabecula is dense, so a guide pin may miss the tract and bend upward. Fig. 4.38 shows the solution to this troublesome problem.
   (a) Skidding the guidewire for a lag screw frequently happens, especially in young patients. Principal compression trabecula is dense, so a guide pin may miss the tract and bend upward. Forceful reaming would damage and break the guidewire (white arrow in Fig. 4.38).
   (b) Withdraw a lag screw reamer and a guide pin. Confirm the damage to the guidewire. If damaged, it must be replaced.
   (c) Then, insert the lag screw reamer through the targeting guide and confirm the AP and lateral view position. If the imaginary extension line from the lag screw reamer hits the intended point in the femoral head, insert the guide pin.
   (d) Tap the end of the guide pin and advance the reaming along the guide pin for a few centimeters. Repeat the procedure if necessary.
   (e) Keep identifying the tip of the guide pin in AP and lateral views.
   (f) Confirm the final position of the lag screw.

Distal interlocking screw insertion can be performed using one of the three methods: a) freehand technique using targeting wand (Figs. 4.39 and 4.40), b) distal targeting device (Figs. 4.11, 4.41 and 4.42), and c) electromagnetic tracking device (Fig. 4.42).

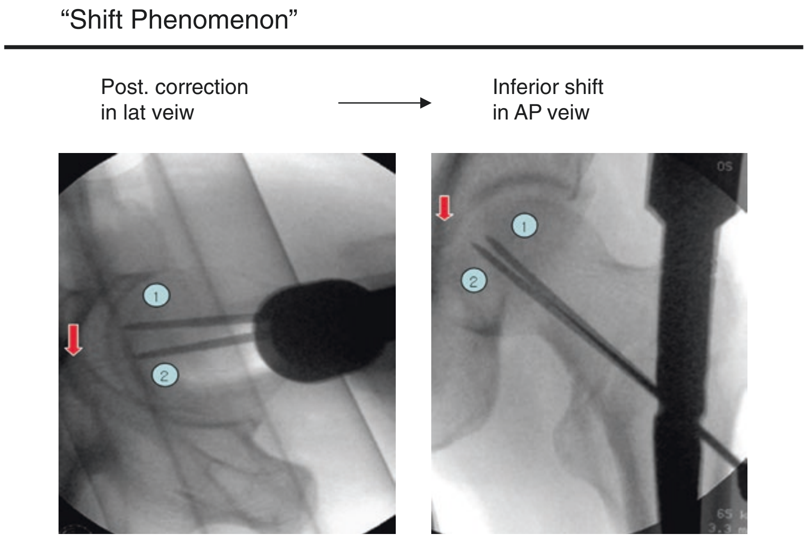

Fig. 4.37 Shifting phenomenon of the guide pin. When the number 1 guide pin is inserted into the center of the femoral head in the AP view but in the anterior one-third of the femoral head in the lateral view, correction is necessary to move the guide pin 1 to the center of the femoral head in the lateral view (number 2). This movement results in inferior migration of the number 1 guide pin in the AP view (final position number 2). Similarly, anterior redirection of the guide pin in the lateral view results in superior migration (shift) of the guide pin in the AP view. This shift phenomenon becomes bigger in severe anteversion [37]

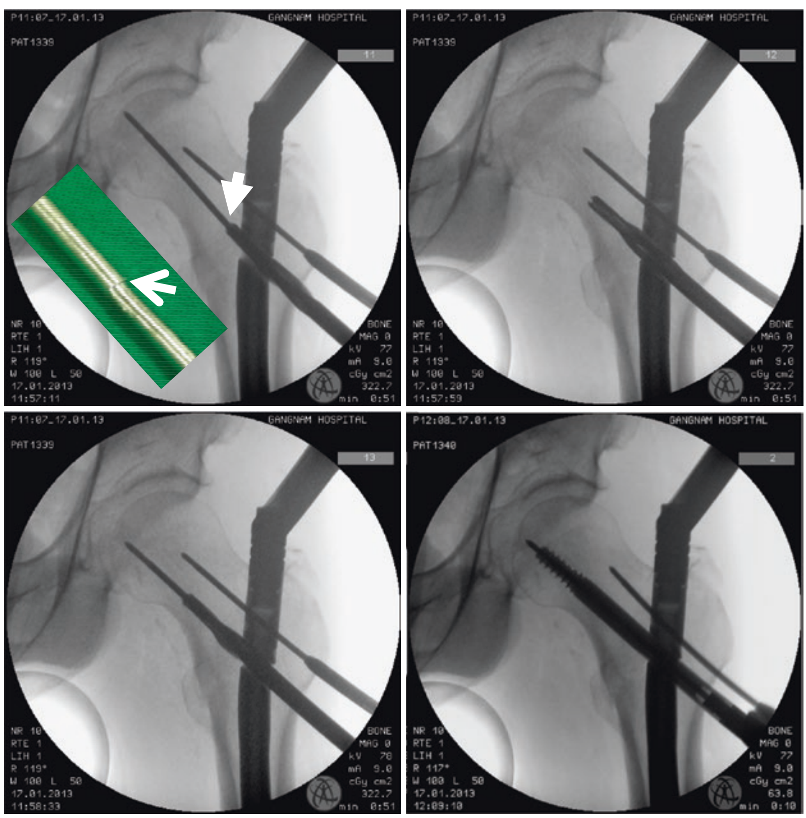

Fig. 4.38 The method of overcoming the skidding phenomenon of the guidewire caused by primary compression trabecula

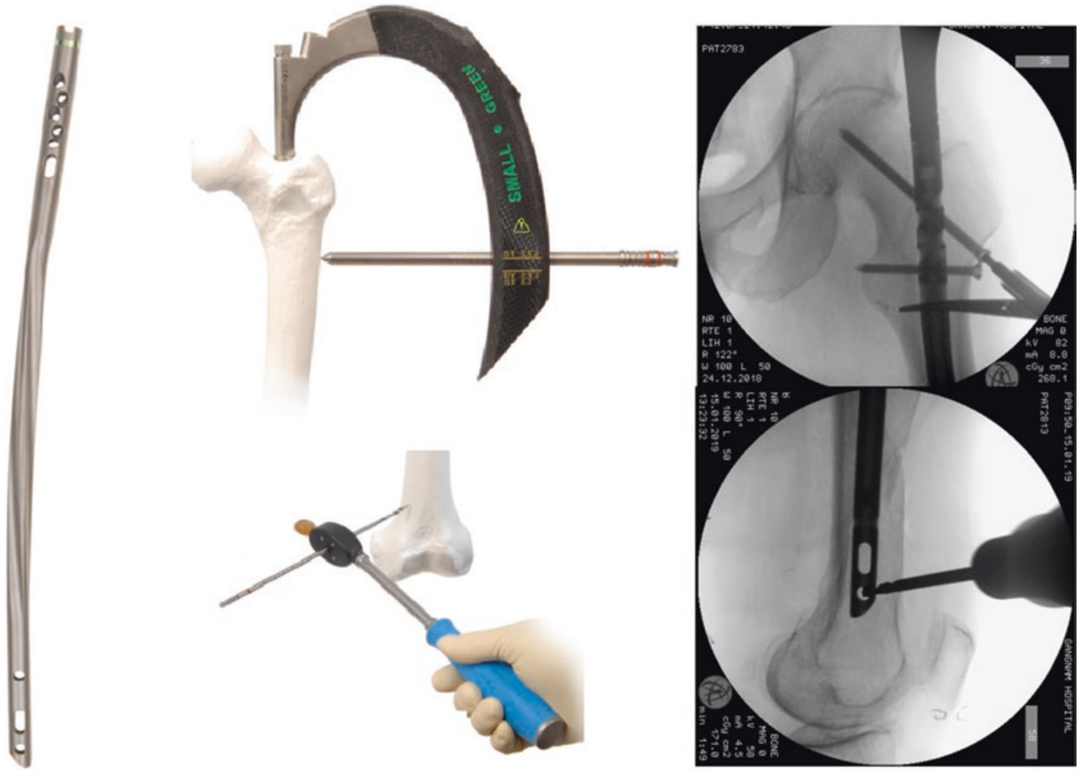

Fig. 4.39 Freehand technique for distal interlocking screw insertion (Targeting of the distal interlocking hole under the control of fluoroscope). Proximal interlocking is performed through appropriate holes in the targeting guide (upper middle and right images). In the distal portion, the freehand technique using a wand is popular. First, adjusting the fluoroscope to visualize the distal hole in a complete circular shape is necessary. Then, the tip of the wand pin or the drill tip is approached to the hole perpendicular to the long axis of the limb or nail (lower middle and right images). Otherwise, the overlap of the nail and the pin interferes with the correct judgment of the tip position. Once the tip hits the center of the distal interlocking hole, tilt the handle to align with the fluoroscopic beam [21]

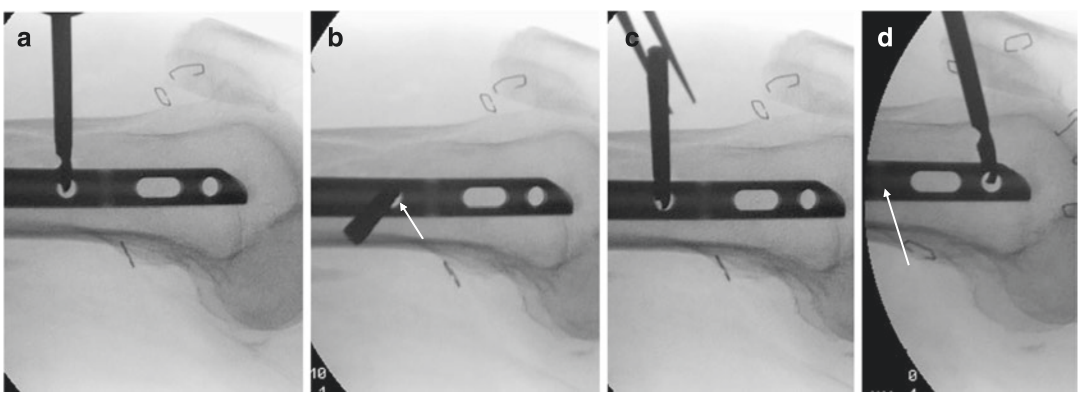

Fig. 4.40 Technique of correcting the misdirected drill bit. Even though the drill tip starts from the center of the circle (**a**), skidding of the tip sometimes occurs, and the drill tip may fail to exit from the interlocking hole (**b**). Disconnect the drill bit from the motor and check the hole using fluoroscopy. There is a small void in the inferior distal part of the interlocking hole (short white arrow). Adjust the drill direction to the void area and restart drilling (**c**). Interlocking hole is made, and the screw is inserted (long white arrow). Interlocking procedure in the most distal hole is more difficult than in the proximal one due to the distance from the starting point to the interlocking hole (**d**)

Fig. 4.41 Distal targeting device. Distal interlocking can be performed with minimal fluoroscopic exposure of the hand if the distal targeting device is available. Usually, slight anterior or posterior adjustment is necessary, and it is convenient to hit the hole with low radiation exposure (Distal targeting system, operative technique, Stryker) [38]

Fig. 4.42 The Smith & Nephew TRIGEN™ SURESHOT™. Distal Targeting System is intended to be an intraoperative image-guided localization system. It is a computer-assisted orthopedic surgery tool to aid the surgeon with drill positioning for screws during intramedullary nail implantation [39]

4.7 Summary

Let's review the IM nailing procedures through the following Figs. 4.43, 4.44, and 4.45.

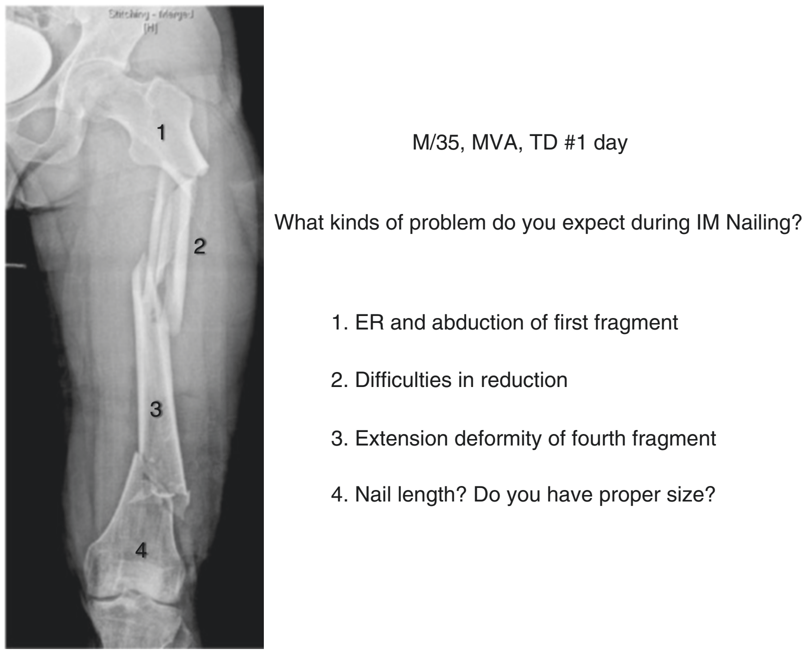

Fig. 4.43 What kinds of problems are expected during IM nailing? What are the tactics for those problems?

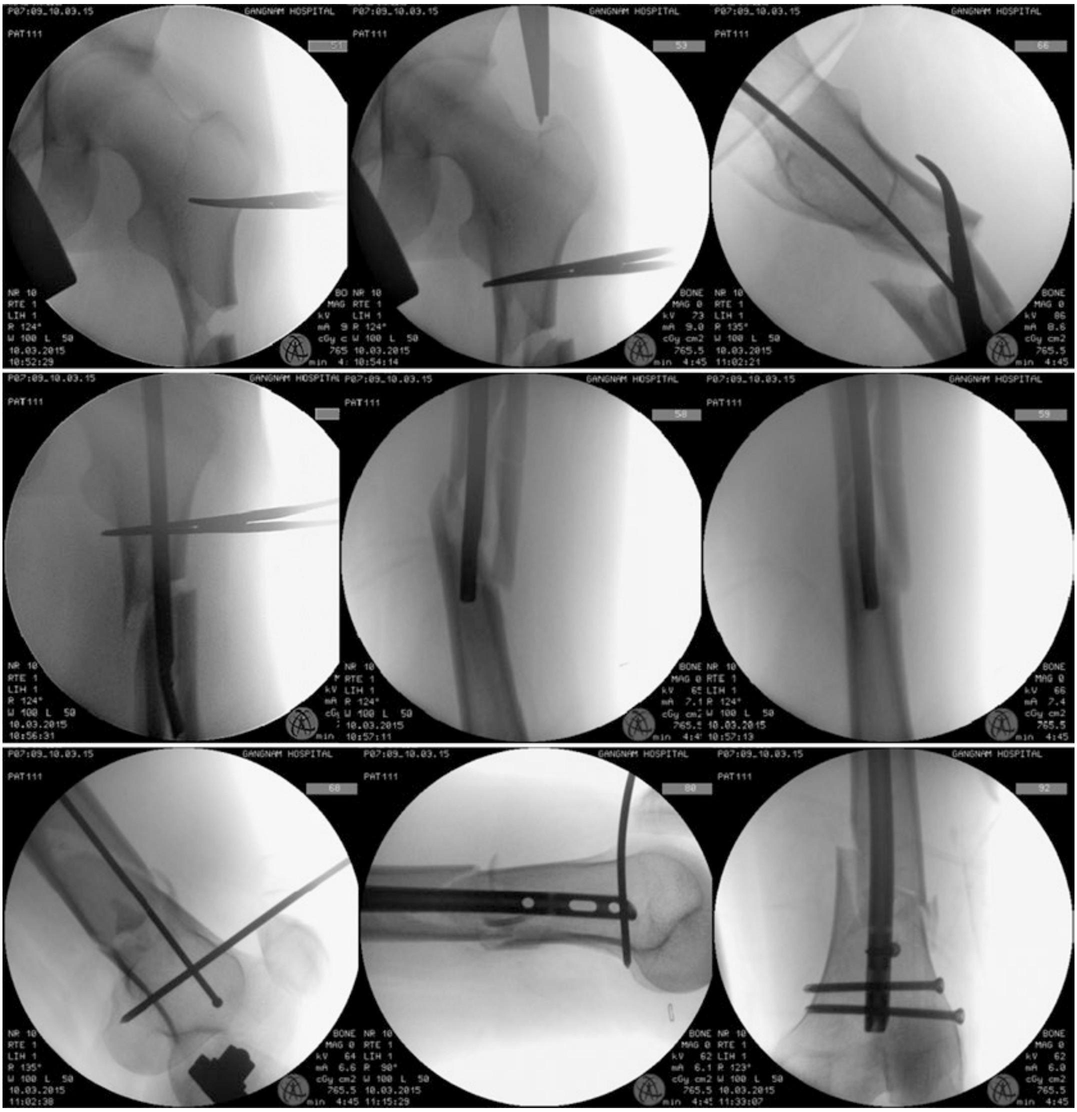

Fig. 4.44 Operation Procedures. It is crucial to derotate the proximal fragment, which is rotated externally. The use of long curved forceps is quite helpful in correcting flexion, abduction, and external rotation deformity of the proximal fragment. First, the deformity of the proximal fragment must be corrected to obtain a proper hip AP view. Then the medial slope of the greater trochanter and trochanteric fossa become visible. Advance the guidewire into the trochanteric fossa and check the lateral view (serial images in the upper column). The entry site is confirmed and reamed the proximal fragment with a trochanteric reamer. Then introduce the reduction finger or similar rod to get proper alignment. Serpentine movement of the curved reduction fingertip can catch the entry of the medullary canal of two middle fragments (serial images in the middle column). The short distal fragment is hyperextended due to heavy gastrocnemius muscle. A Steinmann pin is inserted on the femoral condyle to counteract the gastrocnemius muscle tension to align the distal fragment in the lateral view. The use of a Poller screw in the coronal plane is another option. Keep the reduction until the nail advances to the endpoint as scheduled. The nail was not inserted deep enough into the distal fragment in this case because the longest nail we had was still short for this patient. Insert the distal interlocking screws in AP and latero-medial directions. Two Poller screws could be added besides the nail if the fixation was not firm enough for early knee motion (serial images in the lower column). Check hip AP view in full internal rotation for occult ipsilateral femoral neck fracture and the range of motion of both hip joints to avoid malrotation before the patient leaves the operating room! At the femoral neck, there was no suspicious radiolucent line suggesting an ipsilateral femoral neck fracture in this patient. 15° of femoral anteversion were obtained using inherent anteversion of the femoral nail

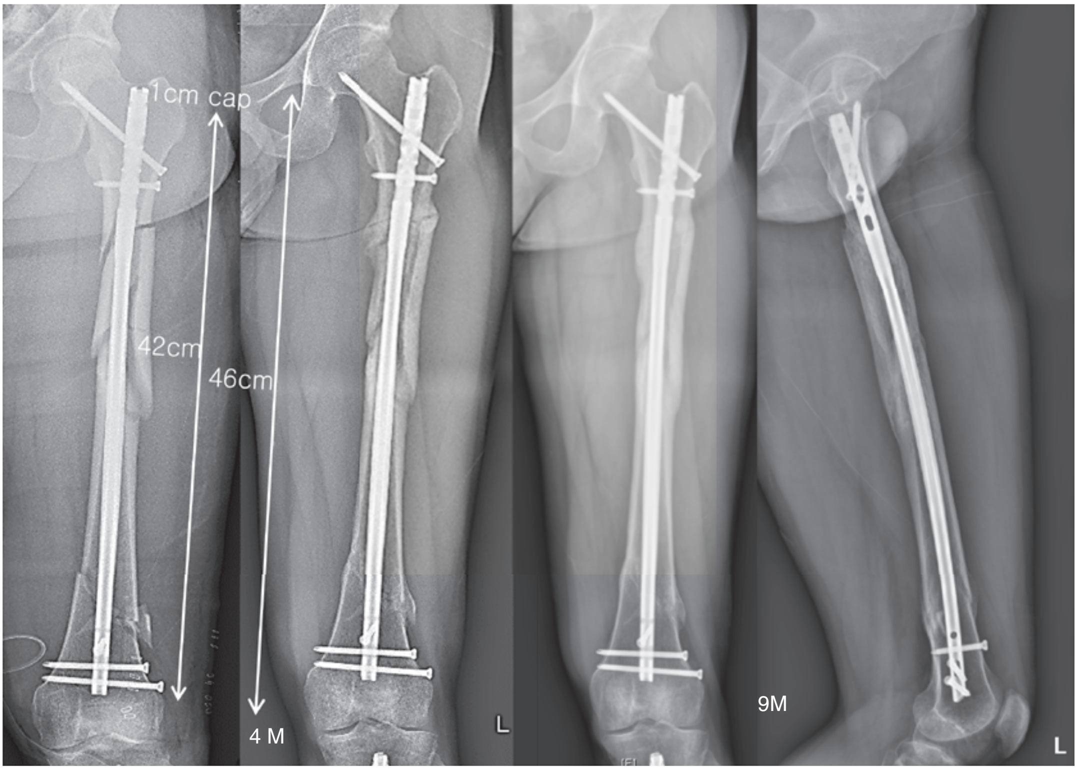

Fig. 4.45 Postoperative and follow-up radiograms. Postoperative radiogram shows the anatomical alignment of the fragments and firm fixation of the proximal and distal fragments. We needed a 46 cm antegrade femoral nail, but a 42 cm nail was the longest one we had at the hospital. The nail tip was not deep enough into the femoral condyle for that reason. Therefore, 1 cm cap was used (we might not be able to put a reconstruction screw into the femoral neck and head if we used a 2 cm cap). Early callus formation is visible 4 months after IM nailing. The solid union was obtained in 9 months

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5 Retrograde Nailing

Chang-Uk Oh

Antegrade nailing has traditionally been the standard technique in most fractures of femoral shaft. Recently, retrograde nailing has been recognized as being equally effective in the treatment of fractures of the femoral shaft, in which the intercondylar notch of the distal femur is used as the entry point [1]. This technique is known to be advantageous for distal one-third and supracondylar fractures. In addition, retrograde femoral nailing has been able to fix femoral shaft fractures, which are associated with other combined musculoskeletal injuries [2, 3].

When it was initially proposed, retrograde nailing used a distal, extra articular entry portal through the medial femoral supracondylar region to fix femoral shaft fracture [4]. It required a bend in the nail and created a large stress riser. With the development of an intra-articular entry portal through intercondylar notch, the results of retrograde nailing have been improved. It has been advocated for the treatment of patients with ipsilateral fractures of the femoral neck and shaft. Its indication has been expanded to include patients with polytrauma, to facilitate the performance of simultaneous or sequential procedures [5].

Retrograde nailing has several technical advantages, such as avoiding the use of a fracture table, easy patient positioning, and relatively short operating time. Accessing the entry portal is easy because of less soft tissue dissection, especially in obese patients. Compared with the entry at the hip for the antegrade nailing, there is no muscle dissection and less exposure to radiation. Bilateral femoral shaft fractures can be simultaneously fixed with the same positioning. Retrograde nailing may be preferred in the presence of a concomitant proximal femoral fracture. It can also be used when proximal access is difficult due to reasons such as a previously placed implant for internal fixation of a proximal femoral fracture [2].

Early results with retrograde nails showed a slightly lower union rate, resulting from using the nails of smaller diameter or unreamed technique [6]. Recent improvements in implant designs and surgical techniques have shown promising outcomes of rapid union and low complications. Problems and complications of entry portal may be equivalent between retrograde (knee symptoms) and antegrade (hip symptoms) techniques [7].

5.1 Surgical Procedures

Patient Positioning

The patient is placed on a radiolucent operating table in the supine position. If needed, the injured extremity (leg) is placed on the height-adjustable Mayo-stand table, which allows for easy visualiza-

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tion by fluoroscopy. The fluoroscope is positioned contralateral to the injured side, which may provide access to the medial and lateral sides of the distal femur. In most cases, manual traction helps to reduce the fracture. Sometimes, a femoral distractor can be helpful. It is useful to have a small sandbag just behind the hip joint to prevent external rotation. This will make subsequent alignment of the distal femoral condyles easier to orientate.

Surgical Approach for Entry Portal

A 4–5 cm longitudinal incision is made on the midline of the palpable patellar tendon. The incision starts at the inferior pole of the patella and ends at the top of the tibial tubercle. The tendon can be split in line with its fibers, and a guide pin is inserted in the midline (Fig. 5.1). The patellar tendon is gently retracted laterally or medially to allow for guide pin insertion. Alternatively, a medial or lateral parapatellar approach is performed. The medial or lateral parapatellar soft tissues are spread longitudinally with scissors.

Under the guidance of image intensifier, the process of locating the entry point is performed. With the knee flexed approximately 30 – 40°, a guide pin is inserted in the midline through the distal femoral cartilage, just anterior to the intercondylar notch. With less flexion of knee joint, the tibial plateau may hinder the guide pin inser-

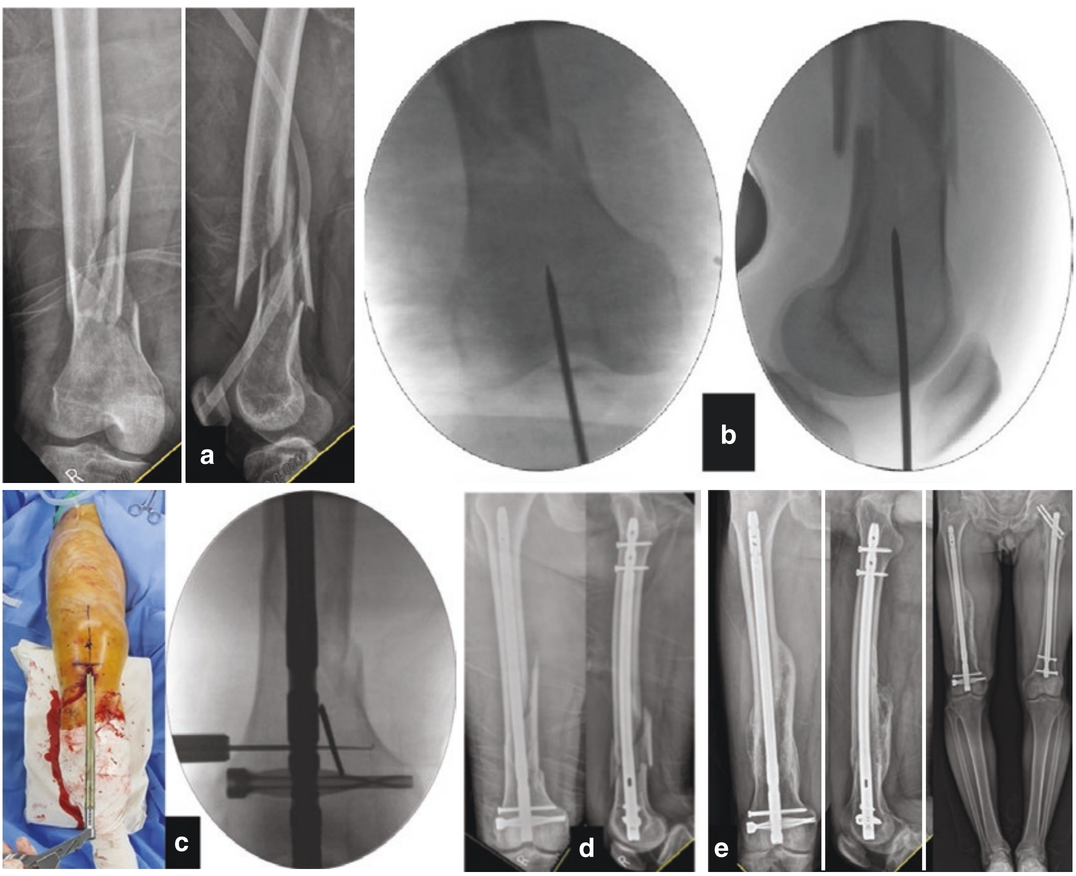

Fig. 5.1 (**a**) Comminuted distal supracondylar femur fracture in a 50-year-old man. (**b**) Anteroposterior and lateral images showing recommended entry point and trajectory of guide pin. (**c**) Using the percutaneous approach through the midline of patellar tendon, the retrograde nail was inserted after reaming. (**d**) Radiographs after reduction of distal femoral fracture and fixation with a retrograde nail. (**e**) A successful healing was achieved in this patient

tion. With more flexion, the articular surface of distal femur may be in danger and the patella is also in the way.

The guide pin should be centered exactly in the middle of the intercondylar notch, on AP projection. It should be located in the extension of Blumensaat's line on the lateral projection. The entry point of the nail should be in line with the axis of the medullary canal, just below the crest of the intercondylar notch. Anatomically, it is located about 1 cm anterior to the proximal attachment of the *posterior cruciate ligament*. It is important not to make the entry point posterior to the Blumensaat's line, to prevent damage to the anterior cruciate ligament when reaming.

When the correct entry point is determined, a guide pin is drilled 5 – 6 cm. The position of the guide pin is confirmed with biplanar fluoroscopic views, in the center on both AP and lateral projections with the fracture aligned. The mal-located entry portal may result in the mal-reduction of fracture. The protection sleeve and drill sleeve are pushed over the guidewire into the notch, to open the medullary canal. Then, the medullary canal is opened to a depth of approximately 30 – 40 mm using the cannulated drill bit. The entry reamer is placed over the guide pin into the distal segment. A sleeve with suction helps minimize osteochondral debris in the knee joint and minimizes trauma to the skin and patellar tendon.

Fracture Reduction

A ball-tipped guidewire is inserted into the distal fragment of the femur. External manipulation of the thigh aligns the relatively mobile distal fragment to the relatively stable proximal fragment. The fracture reduction may be achieved by longitudinal traction applied to the upper tibia. Traction alone can restore the normal length of the bone but may exaggerate the axial malalignment due to muscle forces. A supporting pad or a carbon triangle can be used to help to correct a recurvatum deformity. Percutaneous Schanz pins, used as a joystick method, can also be placed into each segment to assist in reduction of the fracture. Other reduction aids include the reduction clamp or collinear clamp. Percutaneous cerclage wiring may also facilitate satisfactory IM nailing in patients with a spiral or long oblique fracture (Fig. 5.2).

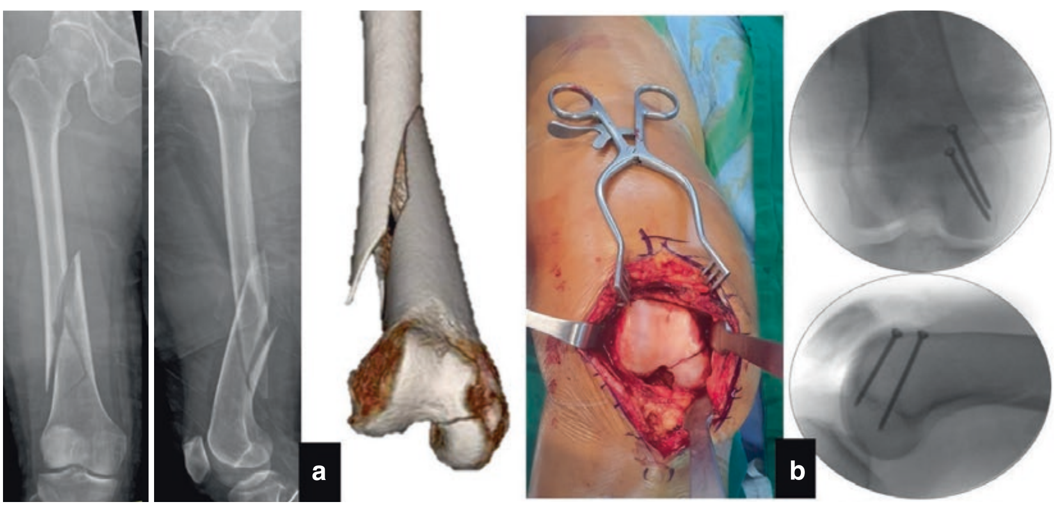

Fig. 5.2 (**a**) A spiral distal femur fracture in a 51-year-old woman. The fracture extended into the articular surface of medial femoral condyle. (**b**) Lateral parapatellar approach was performed, followed by the fixation of medial Hoffa fracture. (**c**) A wire was inserted through the tube of the percutaneous wire passer. Closed reduction of the spiral fracture was achieved by tightening the wire loop. (**d**) Anteroposterior and lateral images show an adequate trajectory of guide pin through the existing parapatellar approach. (**e**) After reaming over the guidewire, the retrograde nail achieved an acceptable reduction. (**f**) Radiographs show an acceptable alignment after retrograde nailing. (**g**) Successful healing was achieved in both intra-articular fracture and shaft fracture of the femur

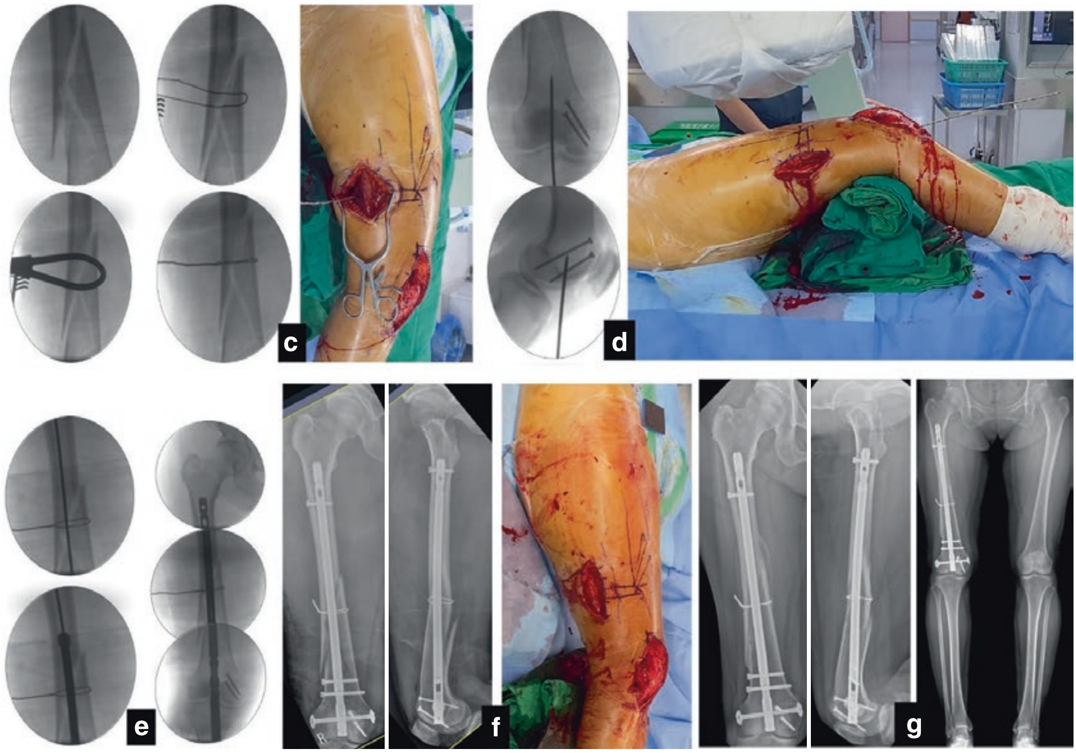

Fig. 5.2 (continued)

The ball-tipped guidewire is advanced across the reduced fracture into the proximal fragment, up to the level of the proximal edge of the lesser trochanter. The measuring sleeve is slid down until it aligns with the entry site, and nail length is measured. After nail length measurement, the ball-tipped guidewire is advanced into the proximal femur so that it is not removed during reaming.

Reaming and Nail Insertion

Serial reaming of the femoral canal starts with an end-cutting reamer advanced to the level of the lesser trochanter while maintaining the reduction. Reaming can progress in 1 mm increments until it reaches cortical chatter and the adequate diameter. It is recommended to select a nail 1 mm smaller in diameter than the largest reamer passed.

The appropriately sized nail is selected and mounted onto the nail-driver assembly. The nail is driven to the desired position using gentle blows while fracture reduction is maintained. Caution is given to the distal end so that it is not over the articular surface. This can be confirmed on lateral projection of fluoroscopic image. The tip of the nail proximally should be at the level of the lesser trochanter. Rotation of the limb is adjusted by comparing it with the uninjured leg, imaging the profile of the lesser trochanter in the injured leg, and matching the rotation of the distal fragment to that of the proximal fragment.

Optional Blocking Screw Fixation and Nail Reinsertion

If fracture reduction cannot be maintained during nail insertion, the nail may need to be removed. Blocking screw (or pin) is then inserted to achieve an acceptable alignment [8]. An image intensifier is used, and the ball-tipped guidewire is left in the femur. For correction of deformity in the sagittal plane, a lateral to medial screw is placed. For correction of coronal plane deformity, an anterior to posterior screw is used. These blocking screws are generally placed in the distal segment of the fracture in the concavity of the deformity using the guidewire and reaming path as a guide. Depending on the location and morphology of the fracture, the blocking screw can sometimes be placed in the proximal segment. Since it works as an artificial cortex, its insertion on the concave side of the deformity can correct angular malalignment as well as translation. Either a conventional cortical screw or an interlocking screw from the retrograde nail set can be selected (Fig. 5.3).

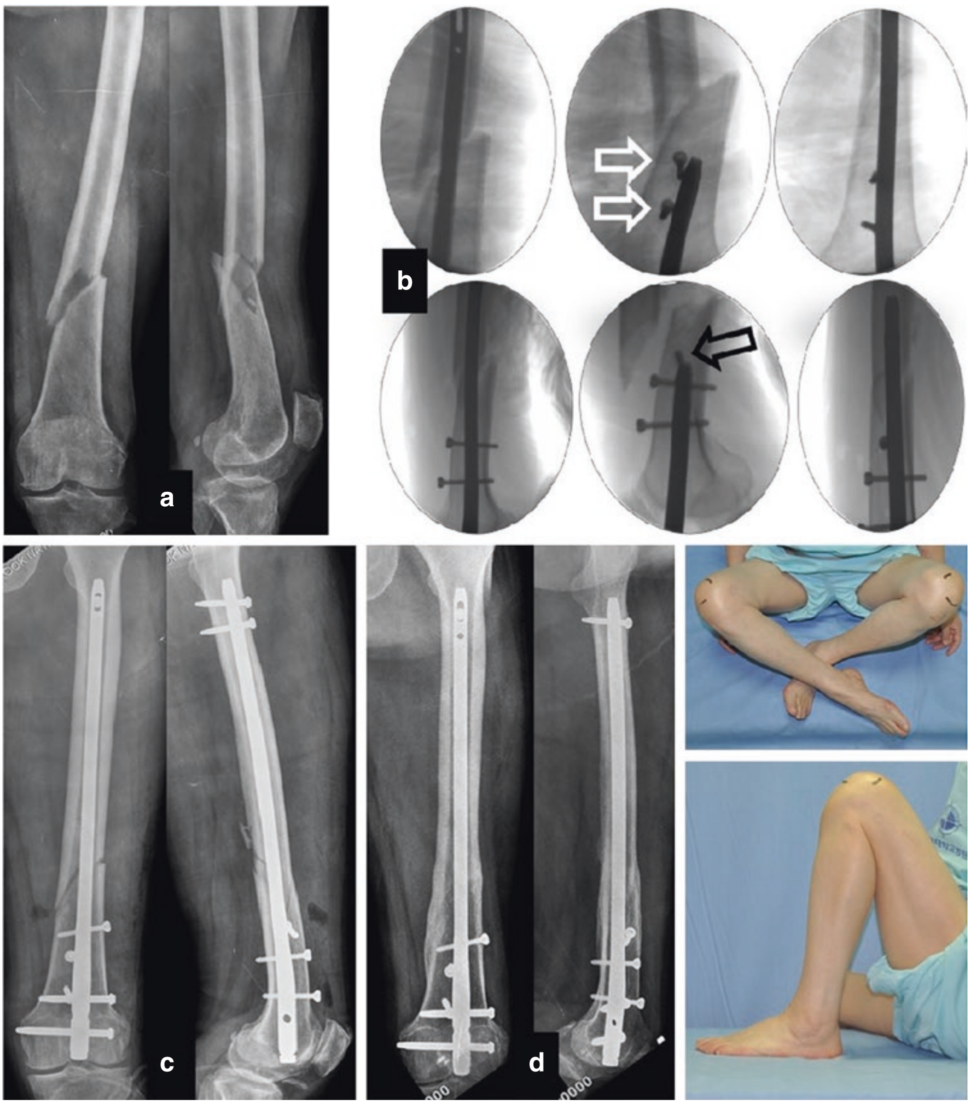

Fig. 5.3 (**a**) A short oblique fracture of distal femur shaft in a 65-year-old woman. (**b**) Unsatisfactory reduction occurred after retrograde nailing. Then, blocking screws improved the reduction quality on AP view. Lateral image also showed a significant translation. Another blocking screw made an acceptable reduction. (**c**) Radiographs showing a satisfactory alignment after the procedure of retrograde nail with blocking screws. (**d**) A successful function and fracture healing was achieved in this patient

After placement of the blocking screw, the medullary canal is reamed, and the nail is reinserted. The reamer must contact the blocking screw, but it should be pushed and passed the blocking screw without reaming to avoid loss of screw purchase or iatrogenic fracture. Exaggeration of the corrected alignment of the femur is often needed to force the intramedullary nail past the blocking screw as it hits the screw [9]. After nail insertion, the reduction is checked again. It is important that the blocking screw does not interfere with the interlocking screw holes of the retrograde nail.

Interlocking and Wound Closure

The distal interlocking screws are placed with the aid of the nail-mounted targeting guide. It is important to judge where the distal screws will be located to allow for maximal fixation in the distal fragment. It should be confirmed that the nail is recessed immediately before placing the distal screws. An incision is made laterally where the drill sleeves meet the skin, and a longitudinal split is made in the fascia lata. The drill sleeve is seated down to the bone. The specific drill bit is used to drill through to the endosteum of the far cortex and length is measured. A maximum of 5 mm is added, and the far cortex is drilled. A depth gauge can be used to confirm the length of the screw. The screw is inserted through the nail with bicortical purchase. The procedure is repeated for the second screw. Oblique and medial-to-lateral screws may be used using the nail-mounted targeting guide when more distal fixation is desired, for instance, in relatively distal fractures.

The proximal end of the nail should not end below the lesser trochanter to avoid creating a stress riser. The proximal AP screws can be placed freehand with fluoroscopy. Correct length and rotation of the fracture should be confirmed immediately before proximal locking. A perfect circle of the hole in the proximal nail in the subtrochanteric zone is obtained using AP fluoroscopy, and the skin over the hole is marked.

Nail cap may theoretically help prevent synovial fluid from tracking into the medullary canal or medullary contents from migrating into the knee joint. *The tip of the nail cap must be 5 mm below the level of the articular surface***.** The use of a nail cap and the instrumentation should be noted in the operation record, which is necessary for its subsequent removal. The knee joint is carefully irrigated to remove all drilling debris, and the wound is closed in layers.

Postoperative Care

At the completion of the procedure, the limb is assessed for length and rotation. Plain radiographs are obtained for the entire femur in two planes and reviewed to assess fracture reduction, implant position, and the absence of intraoperative complications. A thorough examination of the knee joint is also needed to rule out additional ligamentous injuries.

Postoperative management of femoral shaft fractures depends on the extent and severity of associated injuries. Hip and knee range of motion and strengthening exercises are started after 2 days. Most isolated closed fractures can immediately begin treatment with weight-bearing that the patient can tolerate. Partial weight-bearing is permitted with crutches or a walker for the first 6 weeks postoperatively. Restriction of weight-bearing may be needed in cases of extensive comminution of the fracture or combined articular fractures of the lower limb.

5.2 Use of Retrograde Nailing in Clinical Situations

The following are indicated to perform the retrograde nailing:

1. Femoral shaft fractures associated with ipsilateral fractures including femoral neck, acetabulum, pelvic ring, or tibia shaft.
2. Supracondylar fractures of distal femur with or without intra-articular fracture.

3. Infra-isthmic fractures of femoral shaft.
4. Femoral shaft fractures with polytrauma (incl. chest, abdomen, head, etc.)
5. Femoral shaft fractures associated with soft tissue injuries around the hip.
6. Bilateral femoral shaft fractures.
7. Periprosthetic femoral fractures after total knee arthroplasty.
8. Obese patients (severe case).
9. Pregnant women (for protection of the fetus).

Femoral Shaft Fractures Associated with Ipsilateral Fractures Including Femoral Neck, Acetabulum, Pelvic Ring, or Tibia Shaft (Figs. 5.4 and 5.5)

Ipsilateral fractures of the femoral shaft and neck are not common. Although many methods have been tried to manage this injury, there is no consensus regarding their optimal treatment. Antegrade intramedullary nail has been a stan-

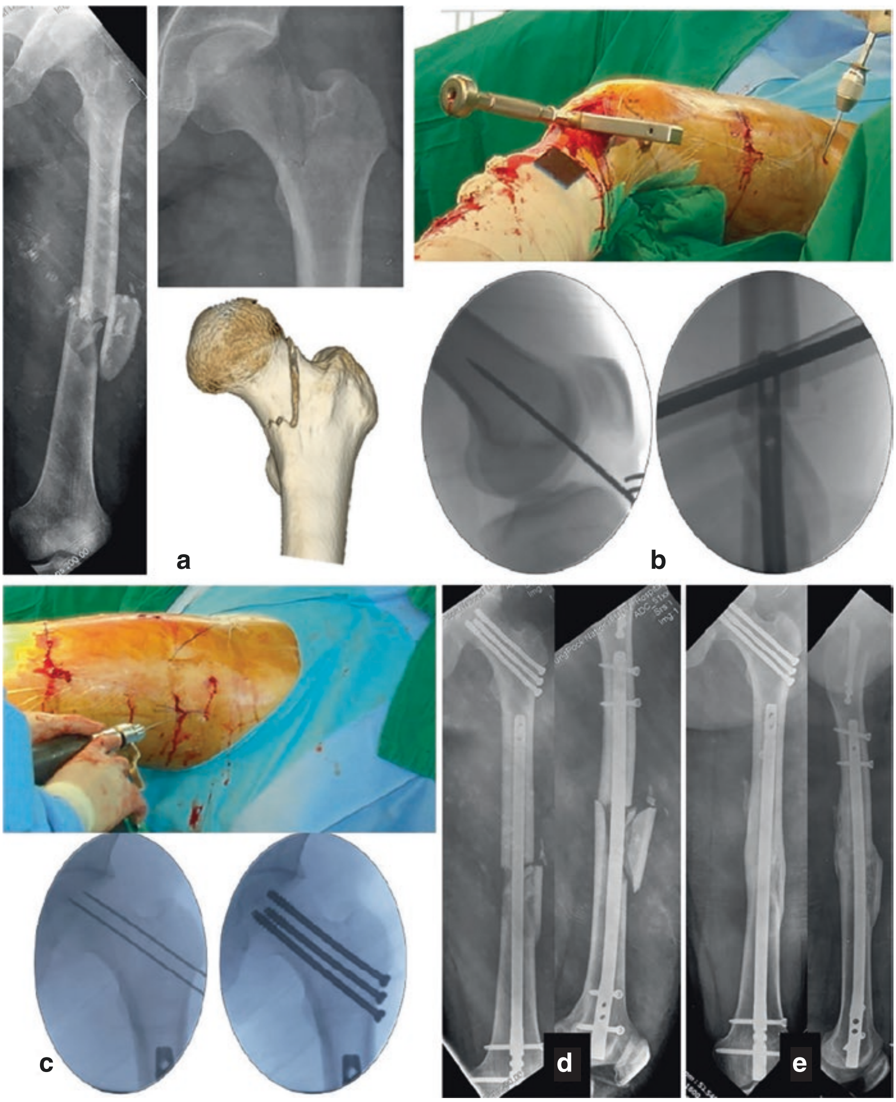

Fig. 5.4 (**a**) A 23-year-old man suffered ipsilateral femoral neck and shaft fractures. 3D-CT image clearly shows the displaced fracture of femoral neck. (**b**) Retrograde nailing was performed. (**c**) Then, three screws were subsequently fixed on the femoral neck. (**d**) Postoperative images show an acceptable reduction and alignment. (**e**) 1 year after operation, all fractures healed uneventfully

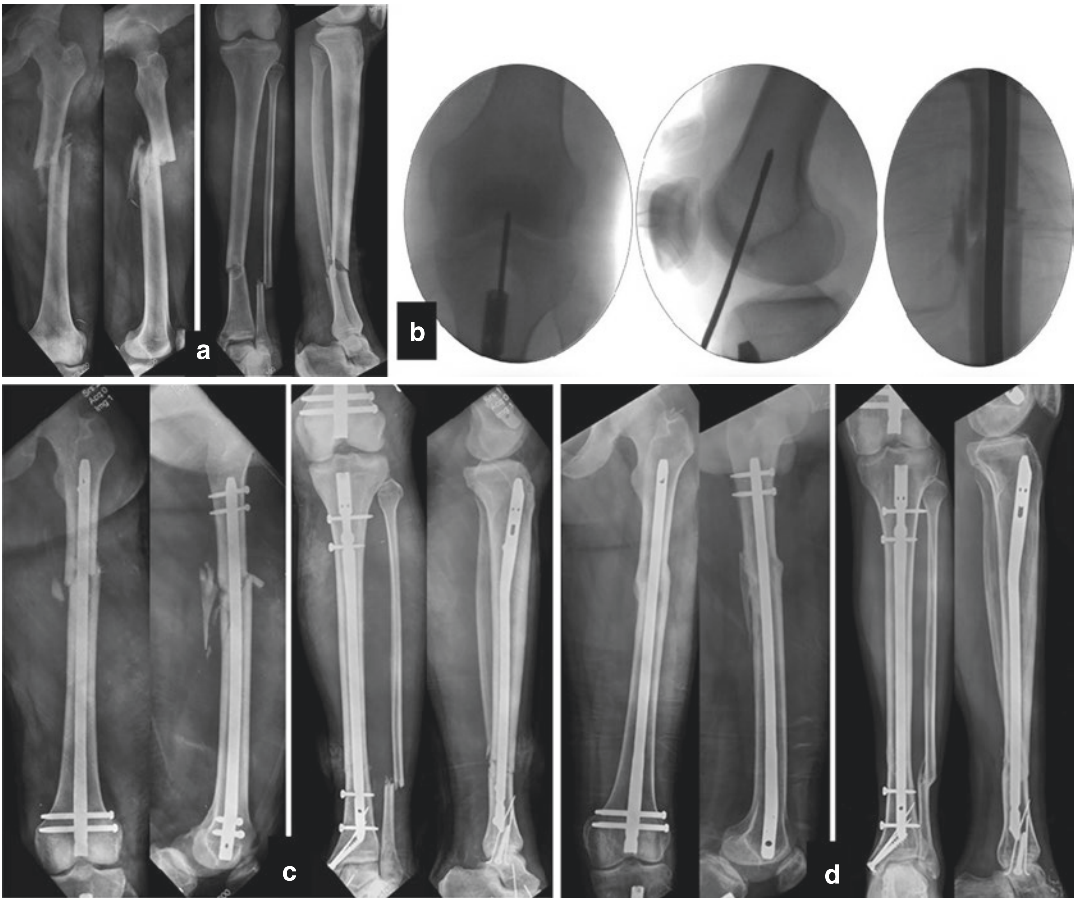

Fig. 5.5 (**a**) Ipsilateral femoral and tibial shaft fractures on the left side. (**b**) Through the adequate entry, retrograde nailing of the femur was performed after tibial nailing. (**c**) Acceptable reduction of femur and tibia on postoperative radiographs. (**d**) Bone unions of both femur and tibia occurred, with good alignment

dard technique in isolated femoral shaft fractures, but it inherently has a hazardous effect on femoral neck fractures in this complex injury [10]. Since the nail entry of antegrade nail nearly coincides with the proximal fracture in this injury, it is difficult to avoid further displacement of the neck fracture and resultant nonunion and/or avascular necrosis of the femoral head [11, 12]. Cephalomedullary or reconstruction IM nail is an attractive solution, as it can fix both fractures with one device. However, its use for this injury is demanding with possible technical errors, which may result in complications especially in the displaced neck fractures [2, 5]. Therefore, retrograde nailing of femoral shaft fracture can be an ideal option for this combined fracture pattern, as it ensures a safe fixation of ipsilateral femoral neck fracture with cannulated or sliding hip screw. (Fig. 5.4).

Infra-Isthmic Fractures of Femoral Shaft

Antegrade IM nailing is currently a gold standard method for the treatment of diaphyseal fracture of the femur. However, it may be difficult to effectively fix the fracture distal to the isthmal level because of widening of the medullary canal. Moreover, because of the relatively short working length in such a situation, complications such as nonunion, malunion, and failure may occur [1].

On the other hand, retrograde IM nailing can achieve a relatively longer working length, and more interlocking screws can be applied to the distal segment. Despite the articular cartilage damage and postoperative knee pain, retrograde nailing is known to offer potential advantage over antegrade IM nailing for infra-isthmic femoral shaft fractures in terms of implant insertion, control of the short distal segment, and fixation strength. When applied to polytrauma, this technique may help to reduce the surgical difficulty and operation time (Fig. 5.6).

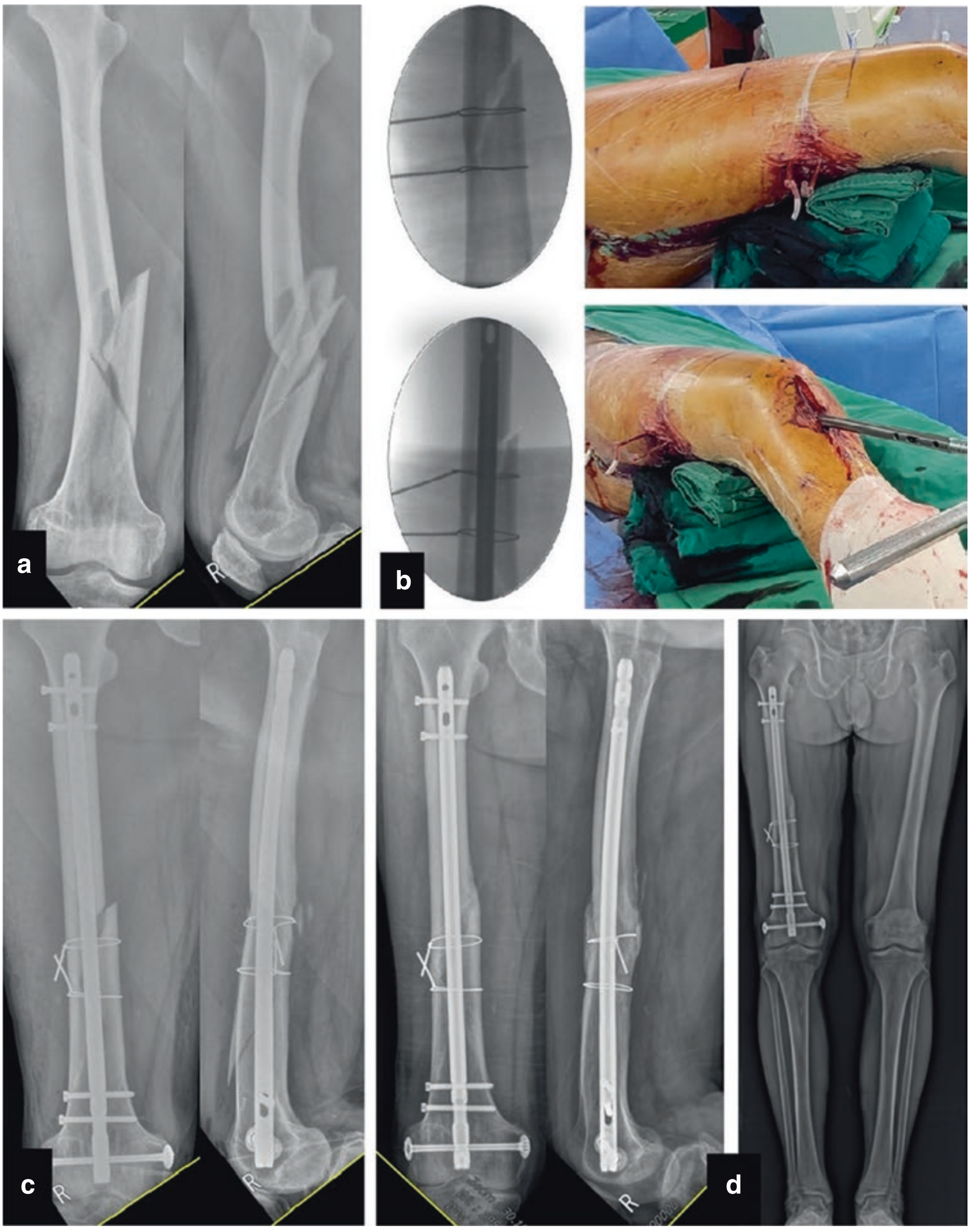

Fig. 5.6 (**a**) A spiral fracture of femoral shaft in a 60-year-old man. (**b**) After percutaneous wiring to reduce the fracture, retrograde nailing was performed. (**c**) Radiographs showing an acceptable reduction after retrograde nailing. (**d**) A successful healing was achieved

The use of retrograde nail in this injury entails several obstacles of malalignment and resultant malunion or nonunion. Like with other metadiaphyseal fractures, the short juxta-articular segment is under the influence of deforming muscle forces, and the large metaphyseal volume does not allow the intramedullary nail to have cortical contact that can aid in the reduction of the fracture. Distal femur fractures typically shorten and displace into recurvatum in the sagittal plane. In the coronal plane, the fractures tend to displace or angulate according to the fracture morphology. Control of an intramedullary nail may be challenging in shorter distal segment of femur. Fractures that occur where the medullary canal is wide are not likely to be reduced by the nail itself because there is less cortical fit.

To overcome the risk of malalignment after retrograde nailing, blocking screws can be placed in the anteroposterior plane to correct coronal deformity or the mediolateral plane to correct sagittal deformity. They are most effectively placed on the concave side of the fracture deformity before or after the procedures of reaming or nail insertion. The blocking screws can aid in reduction of the fracture and augment the strength of the construct as well. These screws effectively decrease the intramedullary diameter of the metaphysis and act as an artificial cortex to aid in reduction of the fracture and placement of the nail in a collinear plane with the diaphysis of the bone (Fig. 5.3) [8, 9].

Intra-Articular Fractures of Distal Femur

Retrograde nailing in fractures with an injured articular cartilage may require a great surgical skill and surgeon's experience. It may raise potential problems, including iatrogenic comminution, inability to place sufficient fixation for the articular fractures, and overall insufficient fixation. To achieve a successful outcome, it is important that the principle of perfect articular reductions is achieved before the retrograde nailing is undertaken. The articular surface should be addressed by direct vision and standard interfragmentary compression. Careful insertion of the nail must ensure that the articular surface reconstruction is not disrupted.

As it needs an adequate exposure of the articular surface of the distal femoral condyle, medial or lateral parapatellar approach may be preferable rather than percutaneous approach. Reduction aids may be helpful for the reduction of the articular split. Schanz pin may act as a joystick in the medial and/or lateral femoral condyle. Pointed reduction forceps, or large pelvic reduction clamps, may clamp from medial to lateral across the intercondylar split. After provisional K wire fixation, lag screws are inserted along the periphery of the articular surface of the lateral femoral condyle, going from lateral to medial, in order to compress the intercondylar split. Care must be taken to ensure that the temporizing pins or definitive lag screws used for articular fixation do not obstruct reaming, nail insertion, or interlock screw placement. Once all articular fragments have been stabilized, clamps and temporizing pins are removed for final fluoroscopic images.

After the articular reduction has been obtained and stabilized, attention is turned toward the reduction of the articular block to the shaft segment with the goal to restore an adequate length, alignment, and rotation (Fig. 5.7).

Periprosthetic Fractures of Distal Femur Following Total Knee Arthroplasty

Periprosthetic supracondylar femoral fractures after total knee arthroplasty (TKA) are increasingly common in an aging population. These fractures are often difficult to treat due to limited bone stock, generalized osteoporosis, and short distal segments. Since nonoperative treatment may be associated with high complication rates, periprosthetic distal femur fractures usually require surgical stabilization. It is important to achieve minimally invasive exposure, preservation of the local fracture biology, ability of long implants to span complex fractures, and load sharing fixation to potentially allow

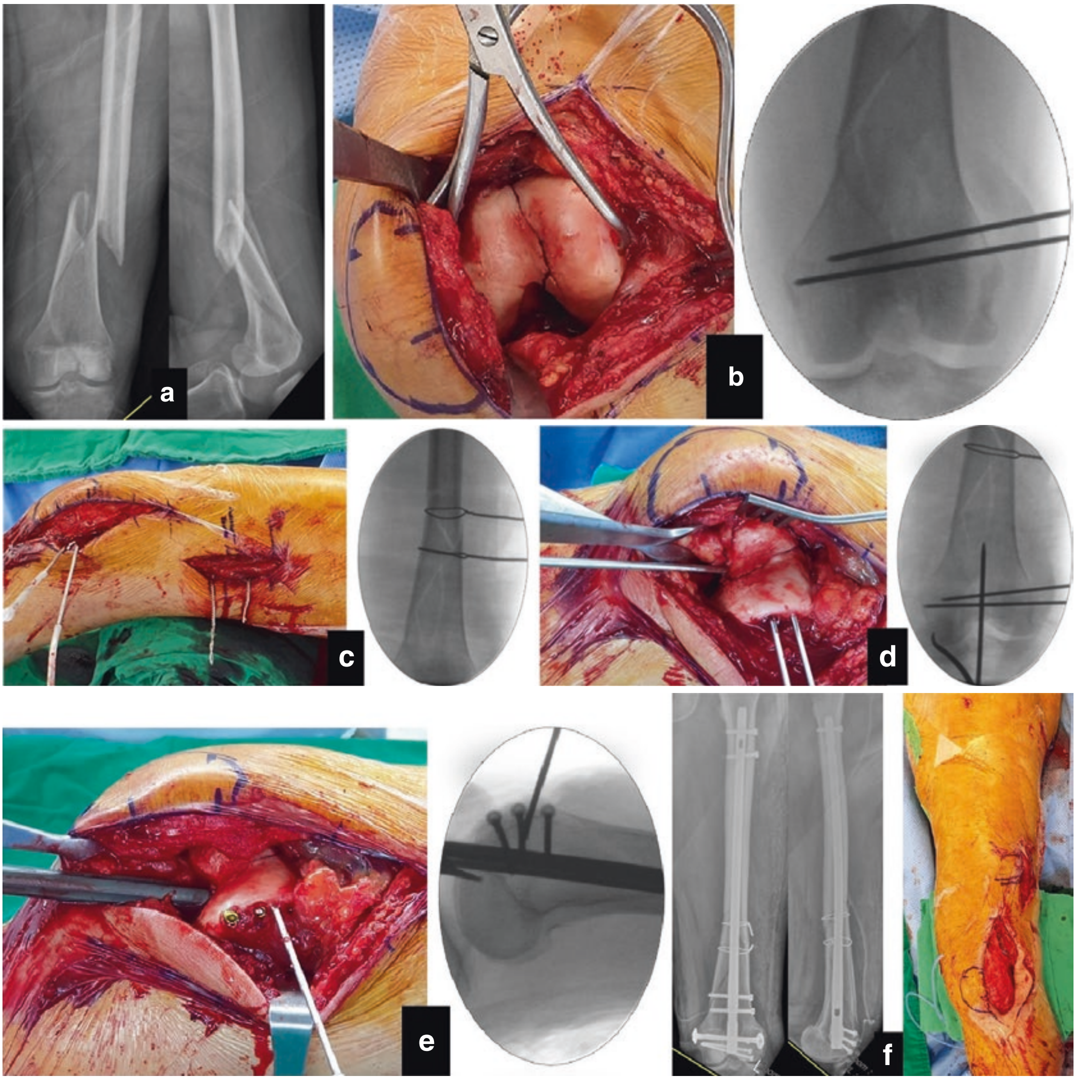

Fig. 5.7 (**a**) A 60-year-old woman suffered a spiral fracture of the distal femur, which extended into the articular surface. (**b**) Using the lateral parapatellar approach, an adequate reduction was achieved with the reduction forceps, followed by temporary pinning. (**c**) Circlage wiring also gained a successful reduction of the spiral fracture. (**d**) Then, the entry was made at the intercondylar notch. (**e**) After the insertion of retrograde nail, interfragmentary lag screws were inserted to fix the femoral condyles. (**f**) Postoperative images show an acceptable alignment. Uneventful healing was achieved in this patient

immediate weight-bearing [13]. Although locking screws can improve the stiffness of the fixation construct, sufficient stability may not often be achieved from the current technique of single-side lateral locked plating in periprosthetic distal femur fracture with osteoporosis or limited remnant of the distal segment. From this viewpoint, retrograde nailing may be an ideal option in periprosthetic distal femur fracture (Fig. 5.8) [14–17].

In surgical procedure, a longitudinal anterior knee incision may be used using the previous arthroplasty scar. After medial parapatellar arthrotomy, the intercondylar notch of the femoral component was exposed, and a guide pin was inserted into the opening of the distal femur. Care

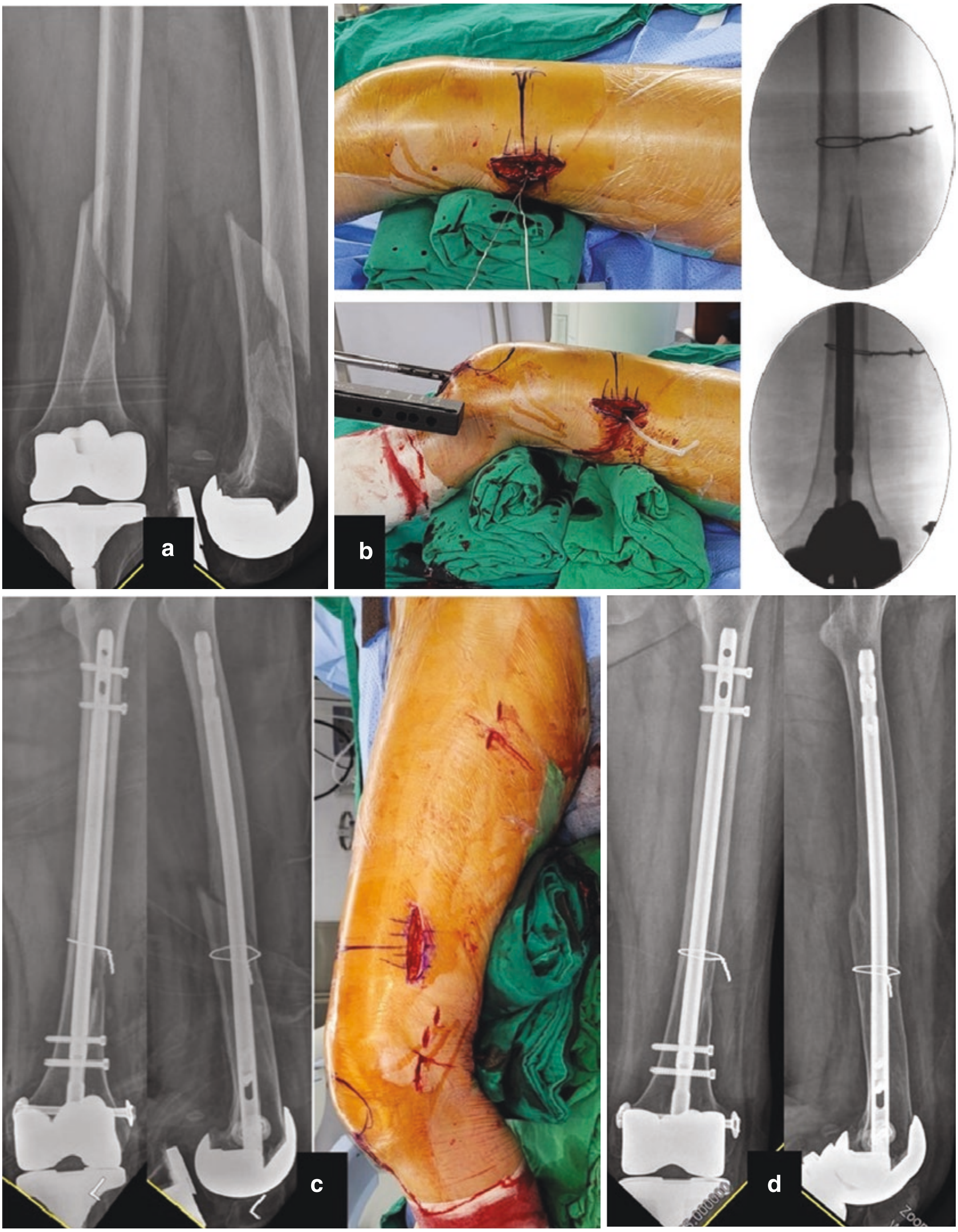

Fig. 5.8 (**a**) A fracture of distal femur around the prosthesis in a 50-year-old man. (**b**) After percutaneous wiring to reduce the fracture, retrograde nailing was performed through the midline approach. (**c**) An acceptable reduction was achieved after retrograde nailing. (**d**) A successful healing was achieved

should be taken not to place an overly posterior nail entry point in the intercondylar notch. It may produce hyperextension deformity of the femoral component. TKA implants with a narrow or posterior notch can make retrograde IM nail placement technically challenging. Preoperative assessment of any preexisting implants is imperative. An ipsilateral hip implant or a closed box femoral TKA component will preclude fixation of retrograde nail [13].

Complications with retrograde nailing include knee sepsis, stiffness, and hyperextension of the femoral component due to an incorrect nail entry point. There is a risk of loosening of distal interlocking screws because of poor bone quality in the periprosthetic supracondylar region. This may lead to the reduction loss after retrograde nailing, and subsequent nonunion or malunion. Recently, the nail-plate combination technique has been tried for the treatment of periprosthetic distal femur fractures, especially in elderly patients with severe osteoporosis. This construct may provide stable fixation to allow for safe, immediate weight-bearing.

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6 Ipsilateral Femoral Neck Fracture

Ipsilateral femoral neck fractures are associated with 1–9% of high-energy femoral shaft fractures. It is usually caused by a head-on car crash, motorcycle accident, or a fall from height. Tremendous force hits the knee joint and travels along the femur to the acetabulum. So, the comminuted femoral shaft fractures are frequently associated with posterior wall fracture of the acetabulum, patellar fracture, supracondylar fracture of the femur, and avulsion fracture of the posterior cruciate ligament as well as ipsilateral femoral neck fracture (Figs. 6.1 and 6.2) [1–7].

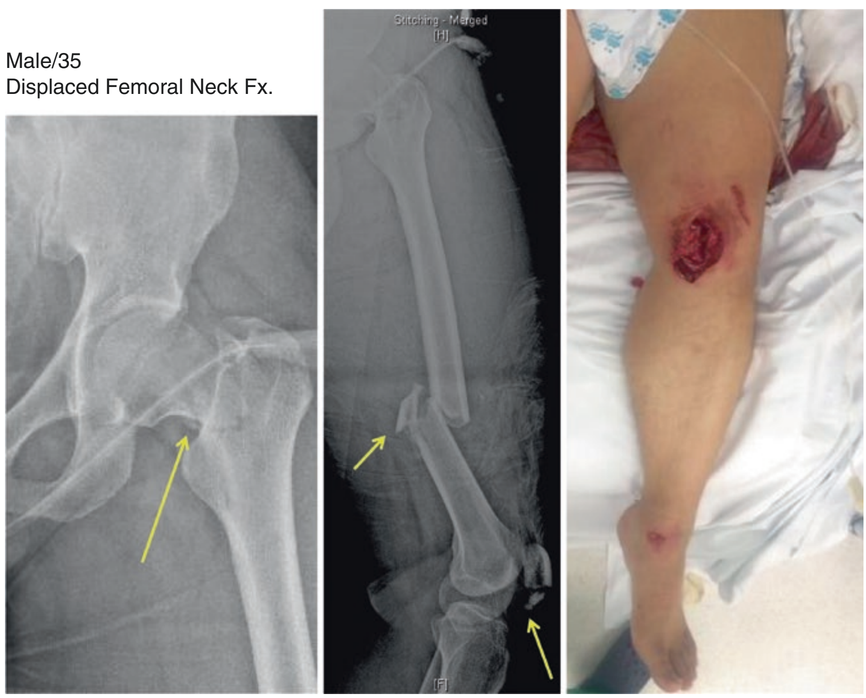

Fig. 6.1 Displaced ipsilateral femoral neck fracture I. A 35-year-old male patient sustained a motorcycle accident. Clinical photography taken at the emergency room shows an open wound at the anterior aspect of the knee joint. Open wound suggests direct impaction on the knee at the accident. An initial radiogram of the hip joint reveals a displaced femoral neck fracture. Femoral shaft fracture is comminuted and associated with open patellar fracture

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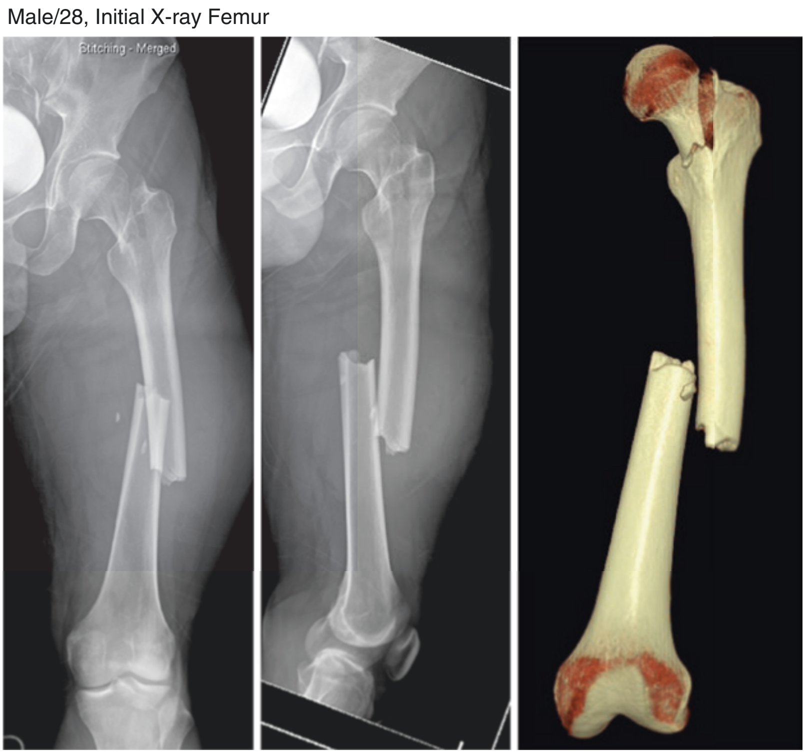

Fig. 6.2 Displaced ipsilateral femoral neck fracture II. External rotation of the proximal fragment hides the displaced ipsilateral femoral neck fracture in the plain radiograms. It is one of the leading causes of missing the ipsilateral femoral neck fracture diagnosis. Until the last decade, CT examination for detecting the ipsilateral femoral neck fracture was not consensus. In the modern era, 3D-CT is quite popular, so you cannot miss the displaced femoral neck fracture. The fracture usually starts from the junction between the superior border of the femoral head and neck. Then, it runs down vertically to the base of the femoral neck at the cervico-trochanteric area

Numerous ways can be applied to treat displaced ipsilateral femoral neck fracture associated with femoral shaft fracture: (1) cannulated screw fixation after closed or open reduction of the femoral neck and retrograde femoral nailing (Fig. 5.4), (2) sliding hip screw fixation and plate osteosynthesis, (3) reconstruction nail fixation after closed reduction, and a combination of the nail plus screw fixation known as a miss-a-nail technique (Fig. 6.3) [1, 2, 6, 7]. *There is no argument regarding the treatment priority*: The displaced femoral neck fracture must be reduced and fixed at first, whatever the treatment methods are applied to the femoral shaft fracture.

What would happen if we missed the displaced femoral neck fracture? Treatment of displaced femoral neck fracture after IM nailing is complicated. Moreover, its result is bad because of nonunion and/or avascular necrosis of the femoral head due to delay in diagnosis. The risk of avascular necrosis is low unless the treatment for the displaced ipsilateral femoral neck fracture is delayed (Fig. 6.4). Swiontkowski et al. (1984) reported that nine patients treated for a displaced ipsilateral femoral neck fracture were followed up for 3 years or more, and two of them developed necrosis of the femoral head [3, 6].

Ipsilateral femoral neck fractures are frequently nondisplaced, and 19–55% are missed on radiographs. Therefore, it has been called occult fracture, nondisplaced fracture, clandestine fracture, and hairline fracture [4, 5, 7]. Numerous articles have been published reporting the neglected ipsilateral femoral neck fractures that were displaced during rehabilitation. The sensitivity of the CT scan in the detection of occult

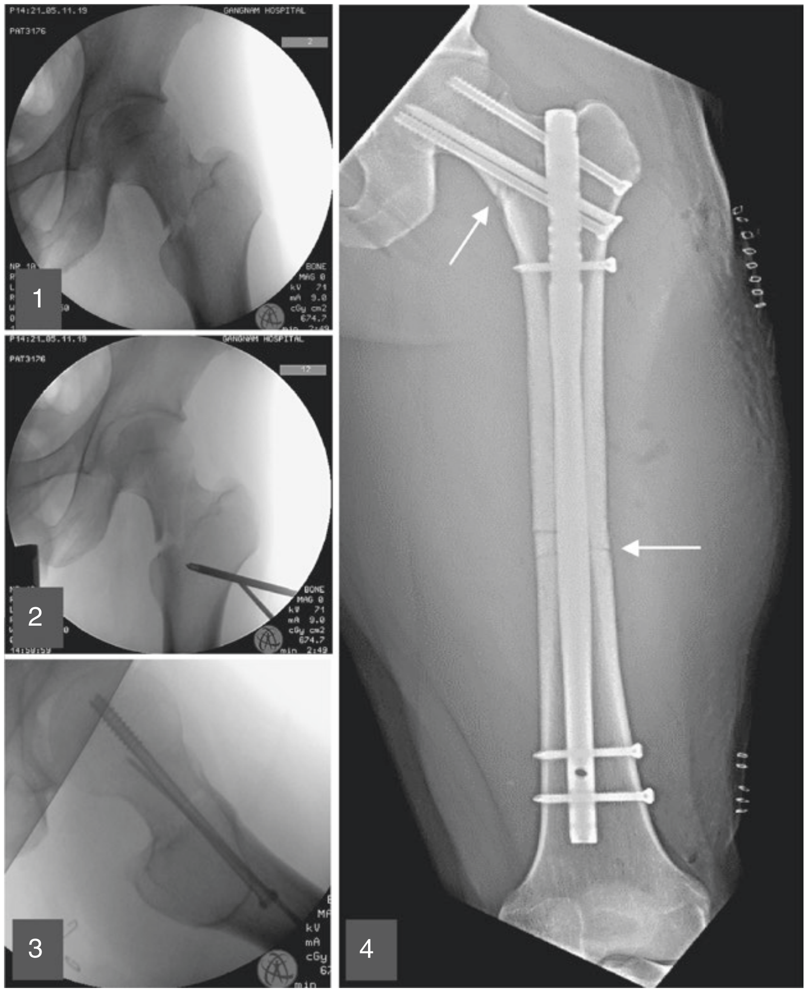

Fig. 6.3 IM nailing treatment sequences for the case mentioned above: displaced femoral neck fracture II (1, 2) The proximal femoral fragment was rotated externally as shown in the 3D-CT in the last figure. A displaced femoral neck fracture was reduced using a Schanz screw inserted in the trochanteric area. Internal rotation of the proximal femur was possible by turning the Schanz screw internally. (3) One provisional pin and one cannulated screw were inserted in the anterior part of the femoral neck after closed reduction. (4) Immediate postoperative radiography showed well reduced femoral neck and shaft fracture [8]

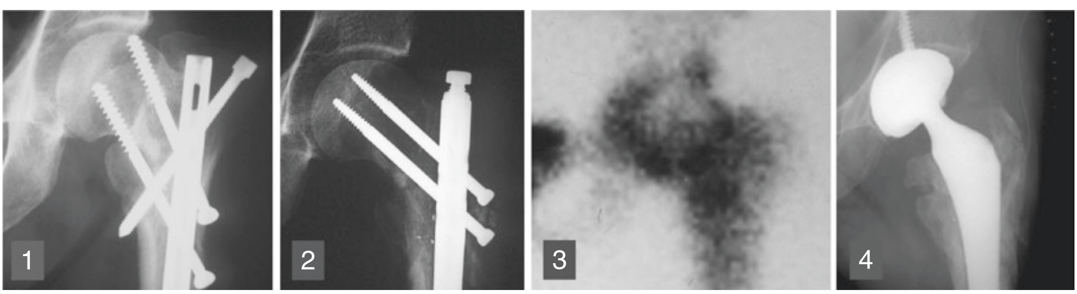

Fig. 6.4 Avascular necrosis of the femoral head after displaced ipsilateral femoral neck fracture. The patient complained of left hip pain for 5 days after IM nailing for femoral shaft fracture. At first, it was regarded as a post-surgical pain. However, the neglected femoral neck was displaced after IM nailing. (1) The surgeon tried to fix the displaced femoral neck fracture using a miss-a-nail technique, but the reduction status was not acceptable. (2) The patient was transferred to our hospital. We removed the preexisting hardware and reduced the femoral neck fracture 1 week after the first operation. The ipsilateral femoral neck and shaft fracture was fixed with a reconstruction nail. (3–4) However, avascular necrosis of the femoral head developed 6 months after the accident and was treated with total hip replacement.

ipsilateral femoral neck fracture seems to be not higher than plain radiography [9]. However, Yang et al. (1998) described the “hairline fracture” at the pelvic CT scan, which was taken to evaluate acetabular fracture on the contralateral side (Figs. 6.5, 6.6, and 6.7) [7].

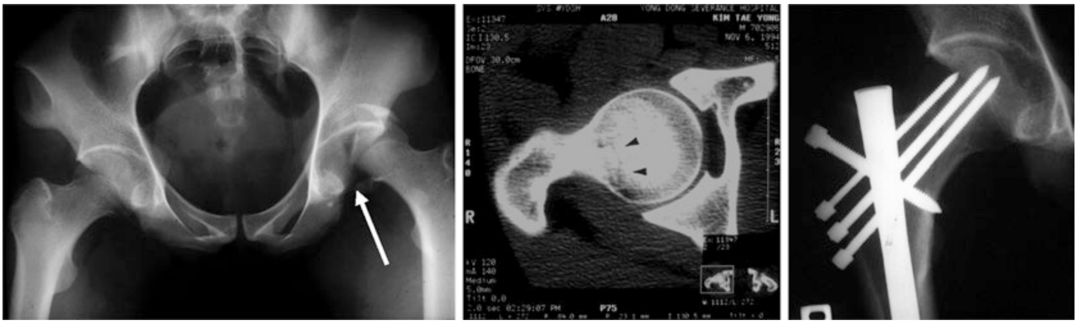

Fig. 6.5 Incidental detection of the hairline fracture on the right femoral neck in the left acetabular fracture patient. A 35-year-old male sustained a motor vehicle accident. Pelvic CT was taken to evaluate left acetabular fracture (white arrow in the left image). A hazy fracture line was identified at the right femoral head and neck junction (two black arrowheads in the middle image). The hairline fracture on the femoral neck was associated with right comminuted femoral shaft fracture. Three Knowles pins were inserted into the femoral neck and head from the anterior half of the proximal femur to prevent displacement during femoral nailing (miss-a-nail technique). Conventional IM femoral nailing was performed after fixation of the undisplaced femoral neck fracture [7]

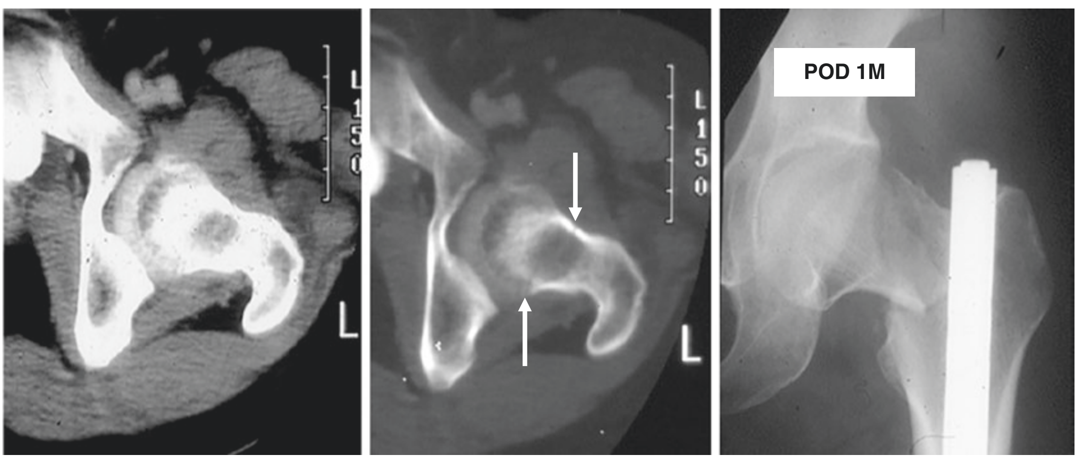

Fig. 6.6 Neglected occult ipsilateral femoral neck fracture. The occult ipsilateral femoral neck fracture was not detected on the plain hip radiography in this 50-year-old female patient who sustained a motor vehicle accident. 1 month after closed IM nailing for left comminuted femoral shaft fracture, the patient complained of left hip pain. Hip AP view reveals a displaced femoral neck fracture. We could review the abdominopelvic computerized tomography (APCT) examination that was taken at the emergency room. The APCT was taken to evaluate the soft organ injury in the abdomen and pelvis. The CT images taken at the soft tissue window showed no fracture line at the femoral neck. However, the CT images of the bony window revealed undisplaced “hairline fracture” at the femoral neck (white arrows). I believe this occult ipsilateral femoral neck fracture has displaced during rehabilitation. If the fracture existed from the beginning, it would have been detected during or after IM nailing in the hip AP view in full internal rotation [7]

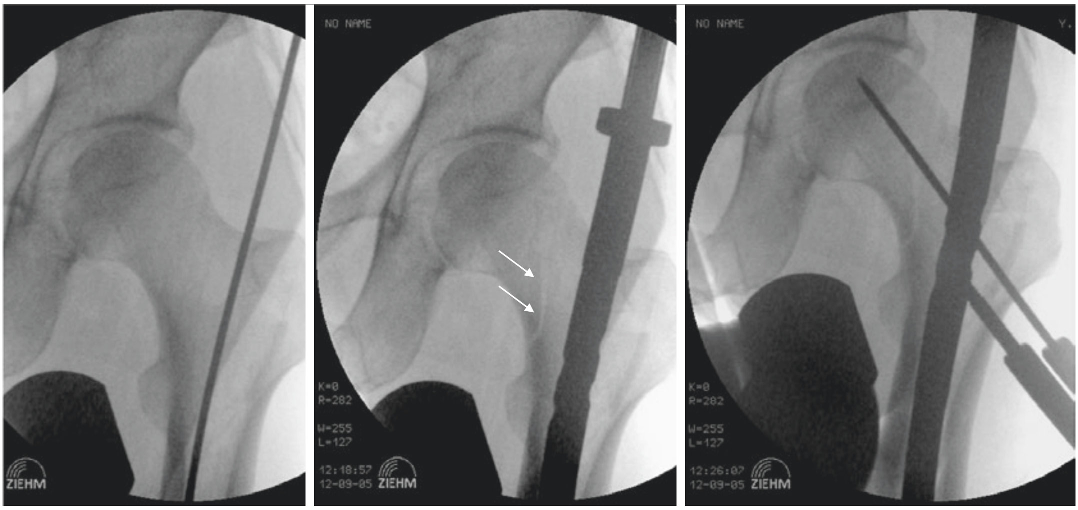

Fig. 6.7 Detection of the occult ipsilateral femoral neck fracture during IM nailing. The full internal rotation of the hip facilitates visualization of the tiny fracture line at the femoral neck in the hip AP view (white arrow). The fracture line was not identified until the final blow for nail insertion. *Confirmation of the hip AP views in the hip internal rotation before the patient leaves the operating room is essential for successful IM nailing*

These days, the preoperative hip CT examination and confirmation of occult neck fracture on the hip AP view in the full internal rotation before the patient leaves the operating room are included in the protocol to prevent the neglected occult fracture. These efforts decreased the cases of neglected femoral neck fracture but could not eliminate the risk [6, 7, 10]. For example, let us look at the case below (Fig. 6.8).

Although a preset bony window setting of dedicated hip CT can be adjusted to a soft tissue window setting in the image viewer, soft tissue window images of APCT are superior to those of dedicated hip CT in detecting a lipohemarthrosis. This is because raw data are reconstructed using a soft tissue kernel in APCT, whereas a bone kernel is used in dedicated hip CT (Fig. 6.9). Fortunately, modern CT machines can reconstruct both soft tissue and bone-kernel images using raw data on demand [7, 11].

The risk of neglected femoral neck fracture was not eliminated completely so two strategies were proposed.

1. Fix the femoral neck in all high-energy femoral shaft fracture cases even though CT is negative in the bone-window image. However, performing prophylactic reconstruction nailing in all high-energy femoral shaft fractures is time-consuming, with an increment of radiation exposure compared with antegrade femoral nailing. It is not cost-effective [13].
2. Perform MRI examination in all CT negative cases. Rogers et al. performed rapid limited-sequence MRI preoperatively for 33 patients who showed no ipsilateral femoral neck fracture on fine-cut hip CT and detected occult ipsilateral femoral neck fractures in four patients (12.1%). Performing MRI for all patients with high-energy trauma and negative hip CT is not easy because of unstable patient status, tight scheduling of MRI scanning, patient discomfort during the transportation (particularly in cases involving multiple fractures), and cost [5, 14–16].

A practical and rational indication for preoperative hip MRI or prophylactic femoral neck fixation remained undetermined. So, we proposed a way to modify these two protocols. We investigated the effectiveness of using the CT capsular sign with lipohemarthrosis of the hip joint as a selective indicator for preoperative hip MRI or prophylactic fixation of the ipsilateral

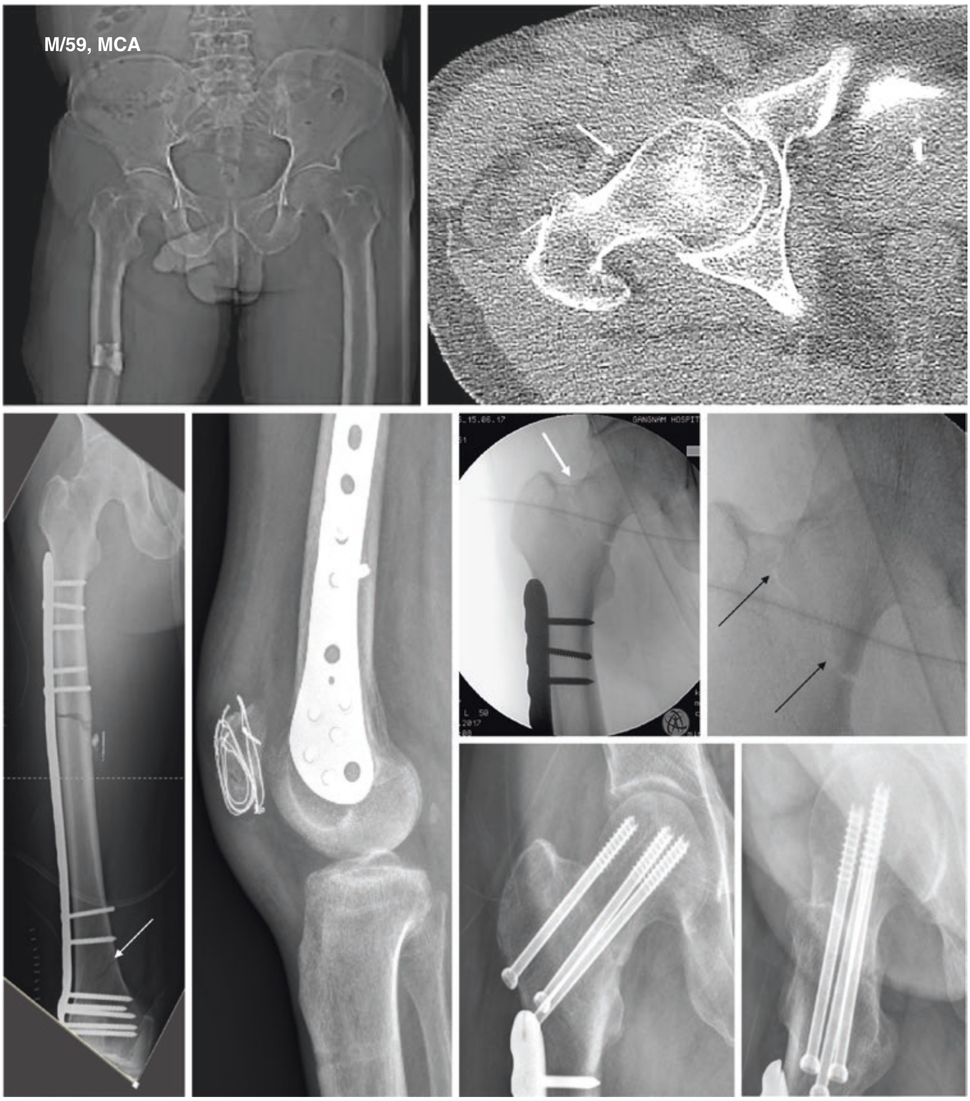

Fig. 6.8 A 59-year-old male sustained a motor vehicle accident. Initial diagnoses at the emergency room were a hemopneumothorax with multiple rib fractures, spleen rupture, segmental femoral shaft fracture, and patellar fracture. We checked the APCT to rule out the occult ipsilateral femoral neck fracture. The hairline fracture was not detected in the hip axial CT images. Due to the chest injury, we decided to perform a minimally invasive plate osteosynthesis (MIPO) for the segmental femoral fracture using the patellar fracture as the distal corridor for plate fixation. After MIPO, the patellar fracture was fixed using the separate vertical wiring technique. Hip AP view in full internal rotation, which was taken at the recovery room, revealed a minimally displaced femoral neck fracture (black and white arrows in the middle column). The patient was again transferred to the operating room and underwent cannulated screw fixation for a neglected femoral neck fracture. The surgeons focused on the fixation of the segmental femoral and patellar fractures and forgot to confirm the hip AP image before the patient left the operating room. We thought that preoperative CT was reliable in ruling out occult ipsilateral femoral neck fracture even though he had several risk factors, such as high-energy injury, supracondylar fracture, and patellar fracture. All the fractures healed uneventfully, but we must think about why we missed the fracture on the preoperative CT. Later, we identified the "lipohemarthrosis of the hip joint" without any clues for the fractures around the joint, including acetabulum. *Unlike hemarthrosis, lipohemarthrosis is a pathognomonic sign of occult fracture, which is located within the joint. Unfortunately, we focused too much on the bony lesion when reading the CT images. When the hairline fracture is not identified in the bony window image, it is necessary to check the soft tissue window image to search for the "lipohemarthrosis"* (white arrow in the upper right image) [7, 11, 12]

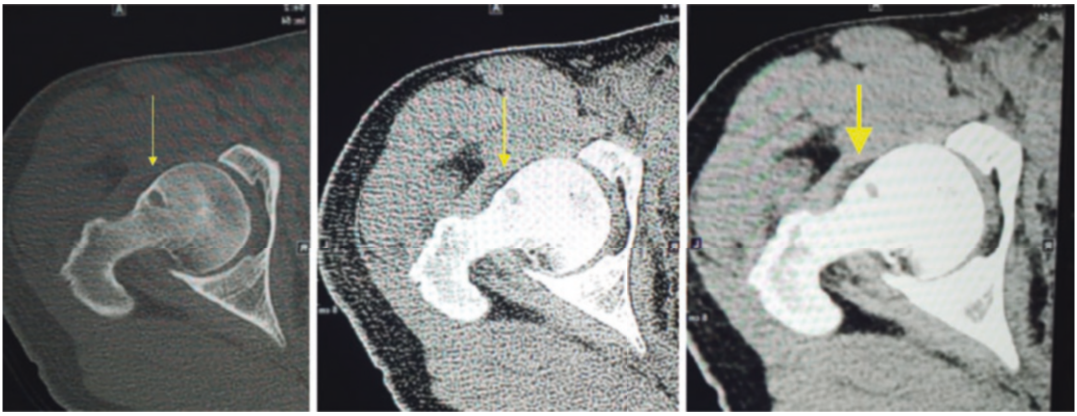

Fig. 6.9 The lipohemarthrosis on bone-window CT scan reconstructed with a bone kernel (left), soft tissue window CT scan reconstructed with a bone kernel (middle), and soft tissue window CT scan reconstructed with a soft tissue kernel (right). The *CT capsular sign* is most distinctive on soft tissue window CT scan reconstructed with a soft tissue kernel (right)

femoral neck in order to prevent unplanned operations resulting from delayed diagnosis of occult ipsilateral femoral neck fractures in patients with high-energy femoral shaft fractures (Figs. 6.10, 6.11, and 6.12) [17].

Based on this study, we came to the conclusion that the use of the CT capsular rsign with lipohemarthrosis as a selective indicator for preoperative hip MRI or prophylactic femoral neck fixation with a reconstruction nail in the patients with high-energy femoral shaft fractures was effective for preventing unplanned surgery caused by delayed diagnosis of the occult ipsilateral femoral neck fractures [17].

Lipohemarthrosis, which consists of blood and fat leaked from the bone marrow through the fracture surface into the joint cavity, is a valuable diagnostic sign of intra-articular fractures. Some intra-articular fractures are only visible on the CT images and not on plain radiography (Fig. 6.13). Unfortunately, undisplaced occult intra-articular fracture is sometimes not detected even through routine CT examination. Detection of an occult intra-articular fracture is crucial because it could be displaced during rehabilitation [20–22].

APCT is an essential diagnostic tool for evaluating high-energy trauma victims and may be performed in multiple phases, often with a 5 min delay between pre-contrast (PC) and delayed phase (DP) images. During this examination, the patients are maintained in a supine position. The separation between fat and blood becomes distinct when the involved limb is immobilized for a given period (e.g., for >5 min), possibly due to the differences in density between blood and fat. We believe a 5 min immobilization of the patient in the supine position facilitates the separation of accumulated fat and blood in the fractured joint and the detection of lipohemarthrosis in the CT axial images (Fig. 6.14) [23].

As an orthopedic surgeon, please pay attention to the delayed or portal phase images of the hip joint in APCT to increase the detection rate of lipohemarthrosis, which is closely related to an occult intra-articular fracture. Unless you find signs of occult ipsilateral femoral neck fracture before the surgery, the detection of femoral neck fracture after IM nailing may let you be blamed for the iatrogenic femoral neck fracture (at least for missing the occult fracture). In the previous study published in 1998, we reported that three

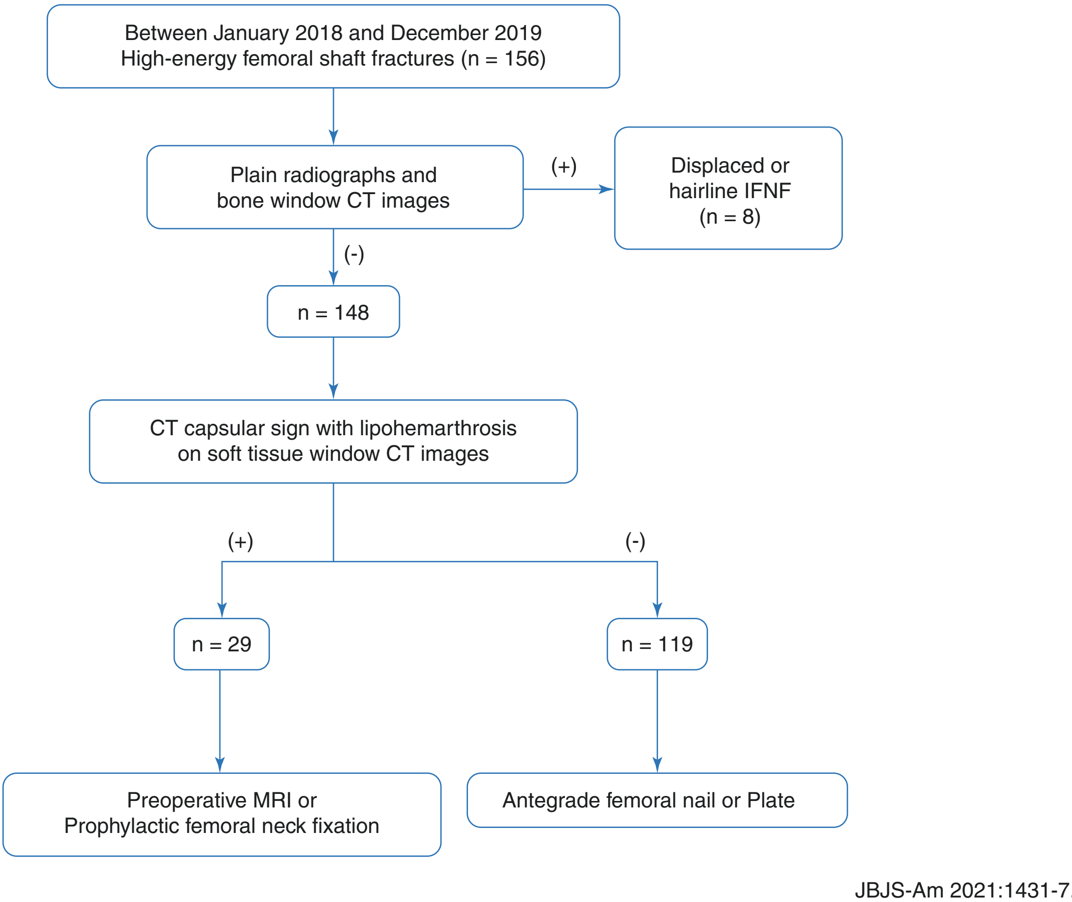

Fig. 6.10 One hundred and fifty-six consecutive patients were included in our study. Eight patients were preoperatively diagnosed with a displaced or hairline ipsilateral femoral neck fracture. In contrast, the remaining 148 patients showed no ipsilateral femoral neck fracture on radiographs and bone-window CT images. On soft tissue window CT images, 29 (19.6%) of the 148 patients had a positive CT capsular sign with lipohemarthrosis. We performed preoperative MRI for three patients; in the remaining 26 patients, prophylactic femoral neck fixation was performed with a reconstruction nail. We identified five occult ipsilateral femoral neck fractures among the 29 patients with a positive sign: two on preoperative MRI scans, two on immediate postoperative radiographs, and one on radiographs made 6 weeks postoperatively. In 119 patients with a negative sign, no occult ipsilateral femoral neck fracture was identified. All occult ipsilateral femoral neck fractures healed without further displacement of the femoral neck. Consequently, additional unplanned surgery for delayed diagnosis of occult ipsilateral femoral neck fracture was prevented [17]

cases out of eight were iatrogenic fractures after IM nailing because the hairline fractures were not identified in the preoperative CT (Fig. 6.15). However, in reviewing these images after 22 years, we found that all three cases showed lipohemarthrosis suggesting these fractures might not be iatrogenic fractures after IM nailing [7, 11, 17]. Unplanned operations to fix the femoral neck fractures could have been avoided if we had used the current protocol, namely MRI examination or prophylactic femoral neck fixation

Iatrogenic fracture of the ipsilateral femoral neck or the greater trochanter occurs in various situations [24–27]:

1. Use the trochanter entry with caution in a patient with valgus femoral neck over 135°.
2. Anterior location of the entry hole.

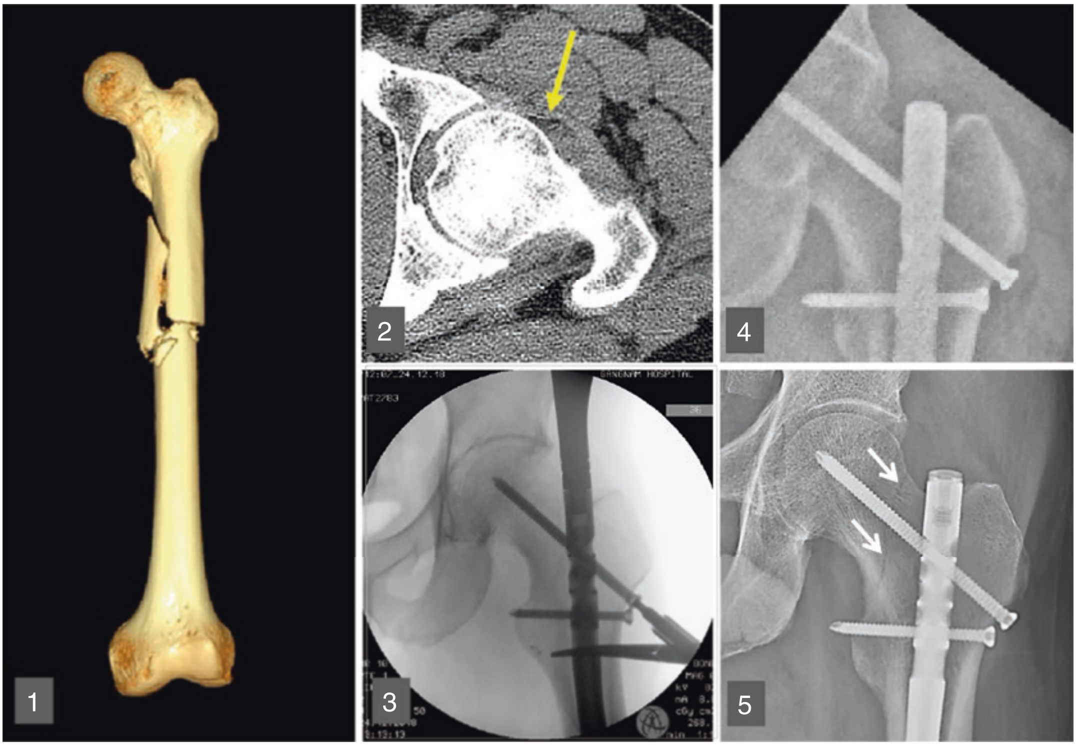

Fig. 6.11 A case of delayed detection of the occult ipsilateral femoral neck fracture. (1) Initial 3D-CT. (2) The preoperative soft tissue window CT scan showed the CT capsular sign with lipohemarthrosis (arrow). (3) Intraoperative fluoroscopic image made during prophylactic fixation of the femoral neck with a reconstruction nail. No fracture was identified in the femoral neck. (4) Immediate postoperative hip radiograph reveals an intact femoral neck. (5) Radiograph made 6 weeks postoperatively, showing a radiolucent line on the femoral neck (two white arrows) [18]. The surgeon may check the femoral neck using dynamic stress fluoroscopy after nail insertion [19]

3. Repeated use of the penetrating device during the preparation of the entry point.
4. Lateral insertion in a small patient.
5. Avoid deep impaction of the nail if the targeting guide proximally has a larger diameter than the nail.

Have you ever heard of a pseudo-ipsilateral femoral neck fracture? The pseudo-fracture was vertically oriented in the middle of the femoral neck thus mimicking a typical ipsilateral femoral neck fracture associated with femoral shaft fracture. After the operation, we realized that it was a pseudo-fracture, so we attempted to determine the causes of the event. We put the patient on the fracture table and recreated the positions we used for femoral nailing, but we could not make the false femoral neck fracture reappear. We then reversed the saved image we took during the operation and found that a radiolucent line ran from the femoral neck to the medial thigh. The boundary of the radiolucent band was a little smoother than that of fracture lines seen in the actual cases (Fig. 6.16). Unfortunately, if the presence of a pseudo-fracture cannot be definitively ascertained, then antegrade femoral nailing must be converted to reconstructive nailing or another method of fixation [28].

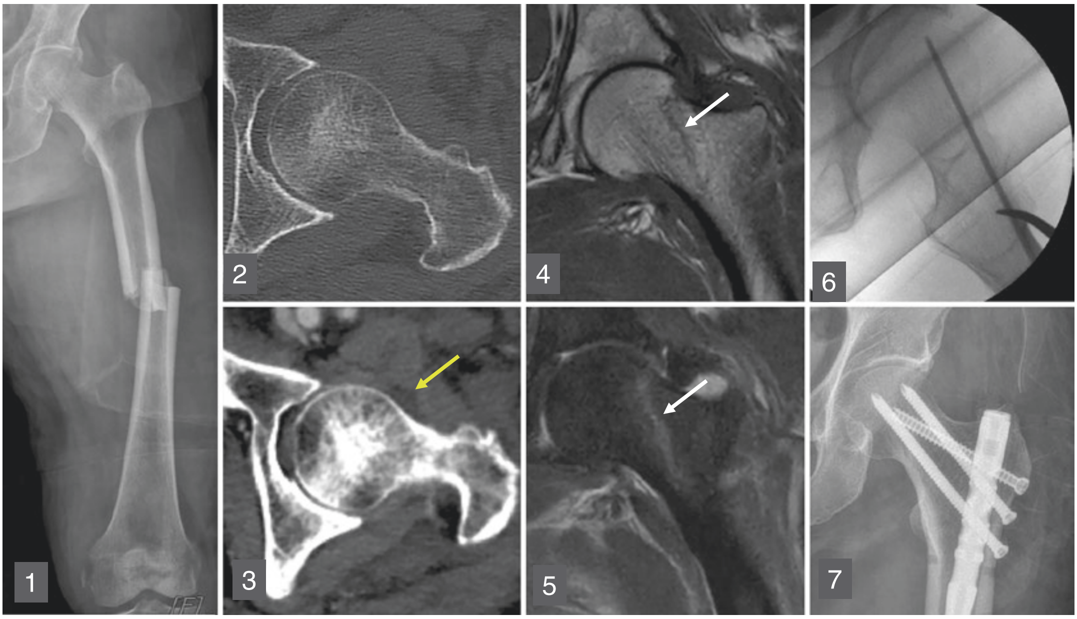

Fig. 6.12 Detection of the occult ipsilateral femoral neck with MRI. (1) Initial radiography showed a mid-shaft femoral fracture. (2) the bone-window CT image failed to identify the hairline fracture. (3) The soft tissue window CT images showed the lipohemarthrosis of the hip joint (yellow arrow). (4) T1 weighted image and (5) fat suppression T2 weighted image of the MRI revealed undisplaced occult ipsilateral femoral neck fracture (white arrow). (6) A guidewire was inserted in the anterior portion of the proximal femur to prevent displacement of undisplaced femoral neck fracture during IM nailing. The wire did not block the entry site. (7) Final radiography after reconstructive IM nailing for the occult ipsilateral femoral neck and shaft fracture

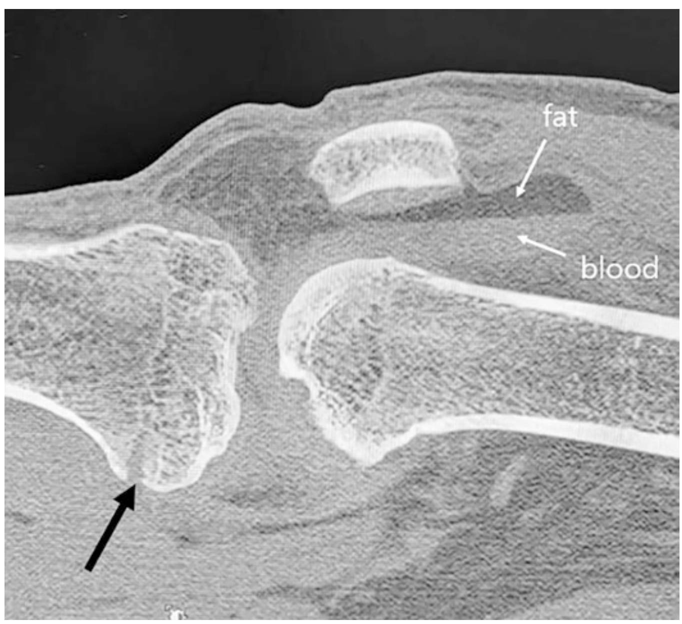

Fig. 6.13 This CT sagittal reconstruction image shows a fat-fluid level that separates the blood and fat within the knee joint in case of the posterior cruciate ligament avulsion fracture (black arrow) patient

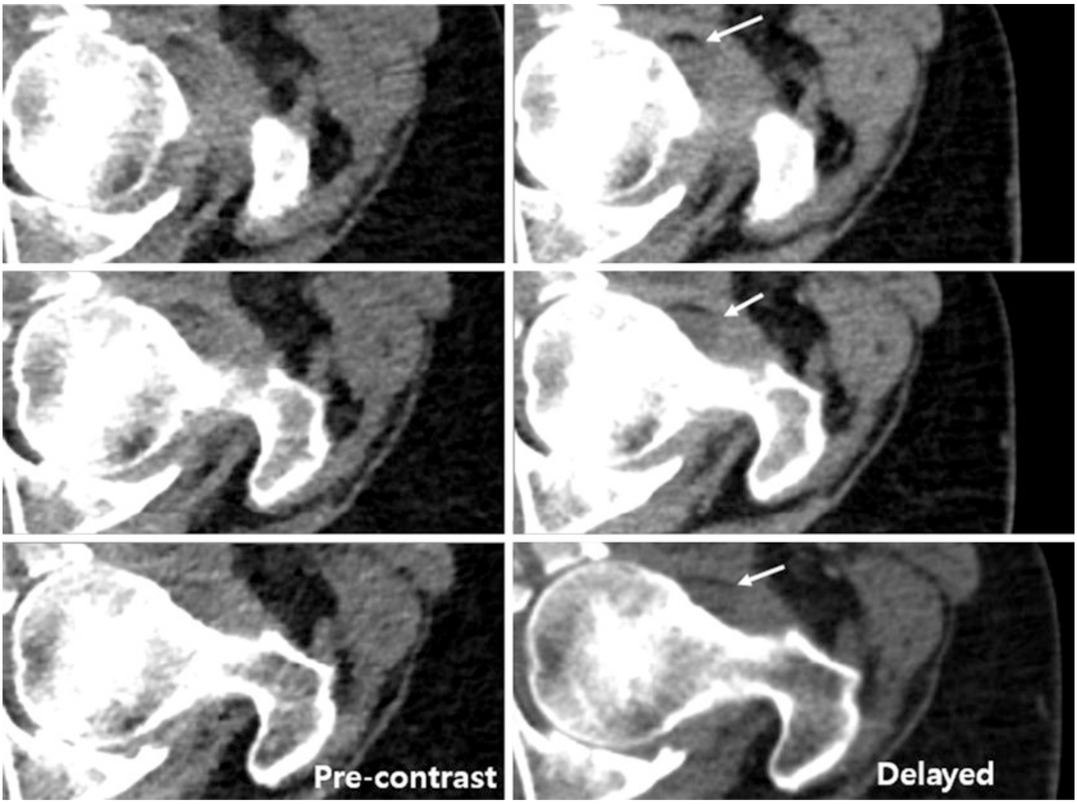

Fig. 6.14 A 5 min delay between pre-contrast and delayed phase CT images facilitates the separation of accumulated fat and blood in the fractured joint and in turn, leads to the detection of lipohemarthrosis in the CT axial images. The arrows indicate the fat-fluid level, which is a sign of lipohemarthrosis

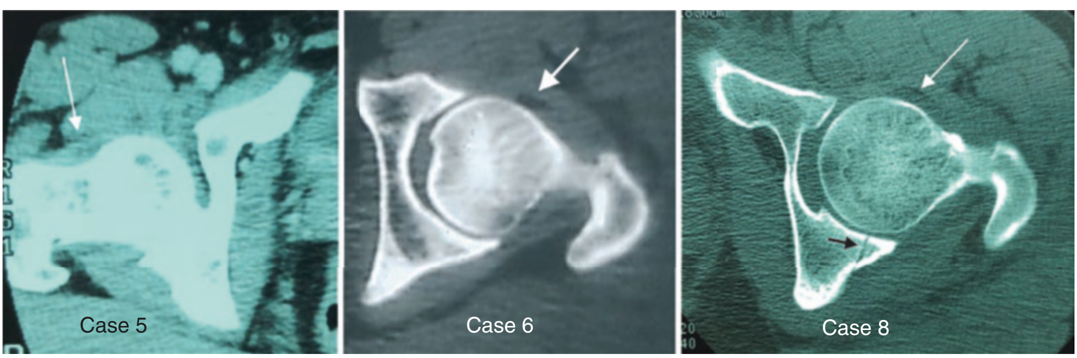

Fig. 6.15 These cases were initially classified as iatrogenic fractures after IM nailing because the hairline fractures were not identified in the preoperative CT images. However, lipohemarthrosis was found in all these cases. This suggests that the initial diagnosis of iatrogenic fracture after IM nailing must be reconsidered. Association of undisplaced posterior wall fracture (black arrow) in case 8 complicates the origin of lipohemarthrosis [7, 11, 17]

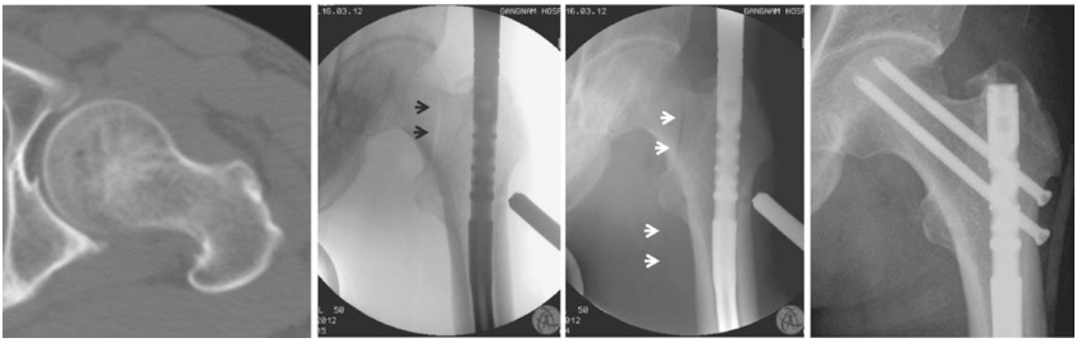

Fig. 6.16 A pseudo-fracture line at the femoral neck during IM nailing. We identified a vertical radiolucent line at the femoral neck (black arrow) during antegrade femoral nailing. Consequently, we decided to switch it to reconstructive femoral nailing. Postoperative hip imaging failed to reveal the femoral neck fracture we had seen in the operating room. Mach bands are a perceptual phenomenon in which dark and bright lines are observed on the borders of structures of different radiographic densities, resulting in contrast-enhancing effects in various areas of the body. Pseudo-fractures are among a group of illusory phenomena that result from overlapping images, differences in background illumination, subjective contour formation, and parallax. Postoperative CT revealed that the pseudo-fracture line shown in the intraoperative reversal fluoroscopic image (white arrowheads) was created by a fat tissue between the fasciae [28]

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7 Bone Defect Due to Open Fracture and/or Infection After Osteosynthesis

IM nailing is an attractive option for the open femoral shaft fracture, especially in Gustilo-Anderson type I and II. After meticulous debridement and soft tissue reconstruction, the indication can be expanded to type IIIa and IIIb open fracture. IM nailing is sometimes performed as nail conversion after external fixation for type IIIa, b, and c open fractures. High-grade open fractures are usually associated with bone loss. Saleeb et al. systematically reviewed the results of IM nailing in the open diaphyseal fracture. Deep infection rate after IM nailing was 6% (95% CI: 3–9.3%) and more prominent in Gustilo type III injuries; The results showed that the odds of deep infection in open Gustilo III femur fractures treated with IM nailing were increased by 3.5 times as compared with grade I and II open fractures. Delayed union rate was 3% (95% CI: 1–5.6%), while malunion rate was 8.4% (95% CI: 5.7–11.6%) [1, 2]. I would not describe the debridement and soft tissue reconstruction methods but focus on the bone reconstruction using IM nailing technique [3, 4]. The strategies for overcoming bone defects after open fractures and/or osteomyelitis are:

1. Ordinary interlocked IM nailing if the defect size is not significant.
2. IM nailing after shortening of the major fragments (for later lengthening).
3. IM nailing with bone defect filled with bone cement (Masquelet technique).
4. Internal bone transport using a monorail type external fixation system.
5. Combination of the external fixator and plate osteosynthesis.

7.1 Ordinary Interlocked IM Nailing if the Defect Size is not Significant

The acceptable size of the bone defect is not known yet and still up to the surgeons' decision. IM nailing is tolerable on a considerable size of defects compared to the plate osteosynthesis because of its central location within the marrow cavity (Fig. 7.1, 7.2 and 7.3). Moreover, the reaming debris may supply osteoinductive and osteoconductive materials. Results of additional autoiliac bone graft are generally good. Treatment of open femoral shaft fracture and acute compartment syndrome of thigh due to gunshot injury is challenging. Patch et al. reported that the ballistic femoral shaft fracture group was associated with a threefold increase in overall complications (30%) compared to the blunt closed femoral fracture group (10%, $p < 0.001$), which had a higher occurrence of thigh compartment syndrome ($p < 0.001$), and required more soft tissue reconstruction ($p < 0.001$) than the closed or open femoral shaft groups. Frequent debridement and early conversion to IM nailing system are recommended [5–10].

K. H. Yang, *The Art of Intramedullary Nailing for Femoral Fracture*,
https://doi.org/10.1007/978-981-19-3730-9_7

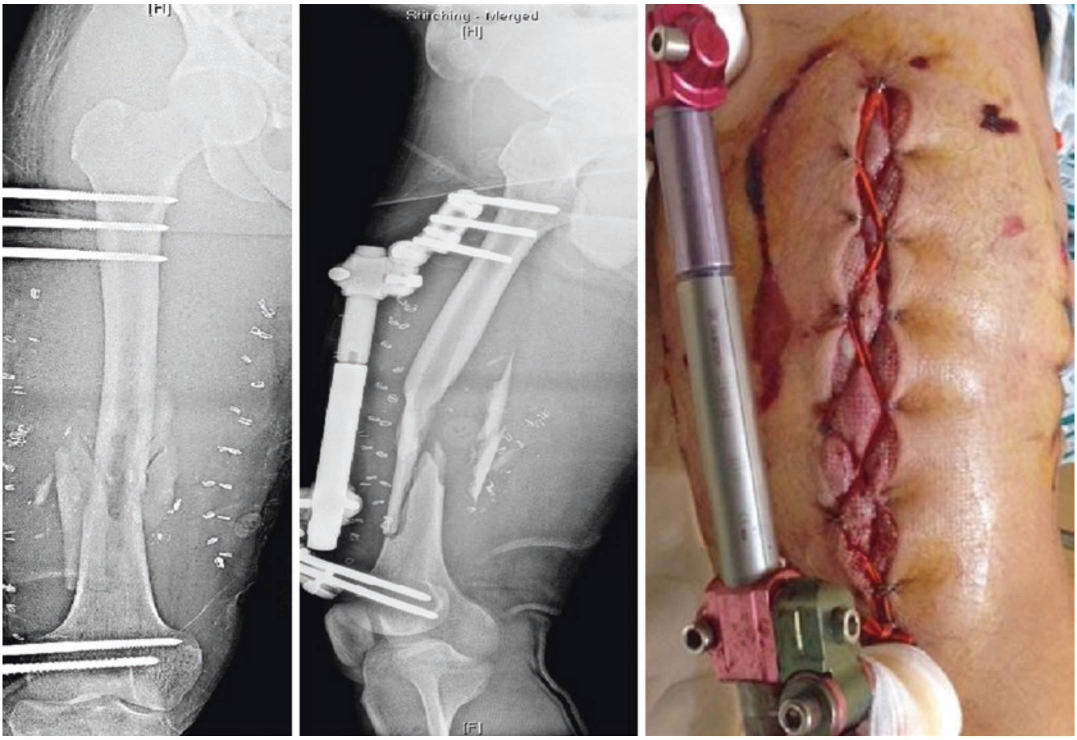

Fig. 7.1 Initial radiograms and a photo of the right thigh. A 27-year male patient sustained a gunshot injury at the right thigh after accidental firing. The bullet smashed the distal one-third of the femoral shaft. Fortunately, circulation, sensory, and motor check-up were intact during the initial evaluation. He was transferred to the regional emergency operating room immediately, and the external fixator was applied after debridement and fasciotomy. Then, he was transferred to our department on the eighth day after the accident

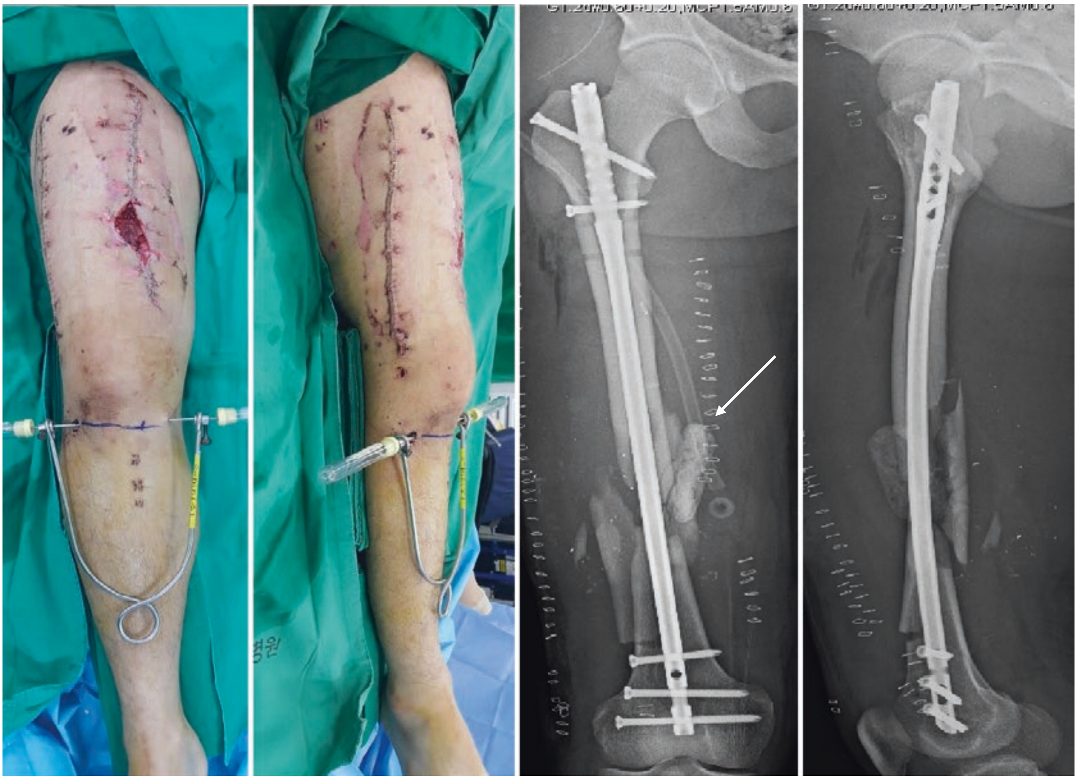

Fig. 7.2 Secondary closure of the fasciotomy wound and subsequent IM nailing. To avoid the pin tract infection, we decided to remove the external fixator and close the fasciotomy wound on the tenth day after injury. Vancomycin impregnated bone cement was inserted through the open medial wound (white arrow). Skeletal traction was applied for 5 days to check the pin site and fasciotomy wounds. Then, IM nailing in a static interlocking mode was performed on the 15th day after the accident. Bone graft was not performed due to the risk of infection at that time. We saved the autoiliac bone graft for later reconstruction after skin graft or secondary closure of the medial wound. The medial wound was closed using the shoe-lace technique and direct suture. The vancomycin impregnated bone cement was removed 1 month after IM nailing

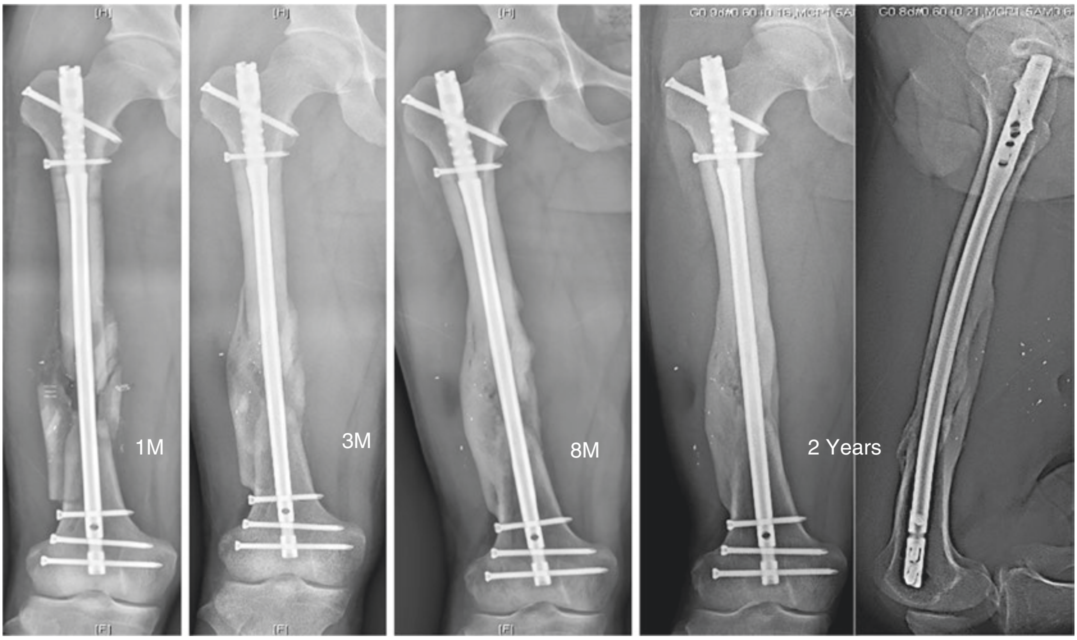

Fig. 7.3 Healing process of the open femoral shaft fracture after gunshot injury. Moderate bone defect around the nail was well recovered with healing callus 3 months after IM nailing and healed 2 years after the accident. Hybrid static interlocking was performed to dynamize the nail in case of a delayed union, but removing the oblique proximal screw was not necessary. The range of motion of the adjacent joints was normal. The femoral nail was removed 2.5 years after the accident

7.2 IM Nailing after Shortening of the Major Fragments (for Later Lengthening)

A combination of the external fixator and nail is an attractive option for treating open fracture with bone loss. The interlocking of the femoral nail makes it possible to remove the external fixator once the injured femur gets the normal length. It shortens the external fixation time and helps reduce the risk of pin site infection (Figs. 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 7.10, 7.11, 7.12 and 7.13). It usually takes just a few months. Additional plate augmentation is at the surgeon's discretion if the defect size is large [1, 11–14]. The grafted bone around the nail consolidates rapidly.

Timely treatments for this Gustilo-Anderson type IIIc open femoral shaft fracture with massive loss of bone stalk made the femur reconstruction possible [15–23]. Fixing two main fragments with a cortical screw was not a usual method, but augmentation was necessary to increase the holding power of the spanning external fixator. Stable fixation was a fundamental requirement for soft tissue recovery (Figs. 7.7, 7.8, 7.9, and 7.10). The short femur was lengthened using a nail and external fixator combination. We wanted to compress the original fracture site during the lengthening of the corticotomy site. The severe scar around the knee joint caused severe stiffness of the knee joint inevitably. Judet quadricepsplasty was performed after the consolidation of the lengthening and fracture site. The final range of motion of the knee joint was 0–100°. Achilles tendon lengthening was also necessary due to long-standing foot drop after peroneal nerve palsy, which never recovered (Figs. 7.12 and 7.13).

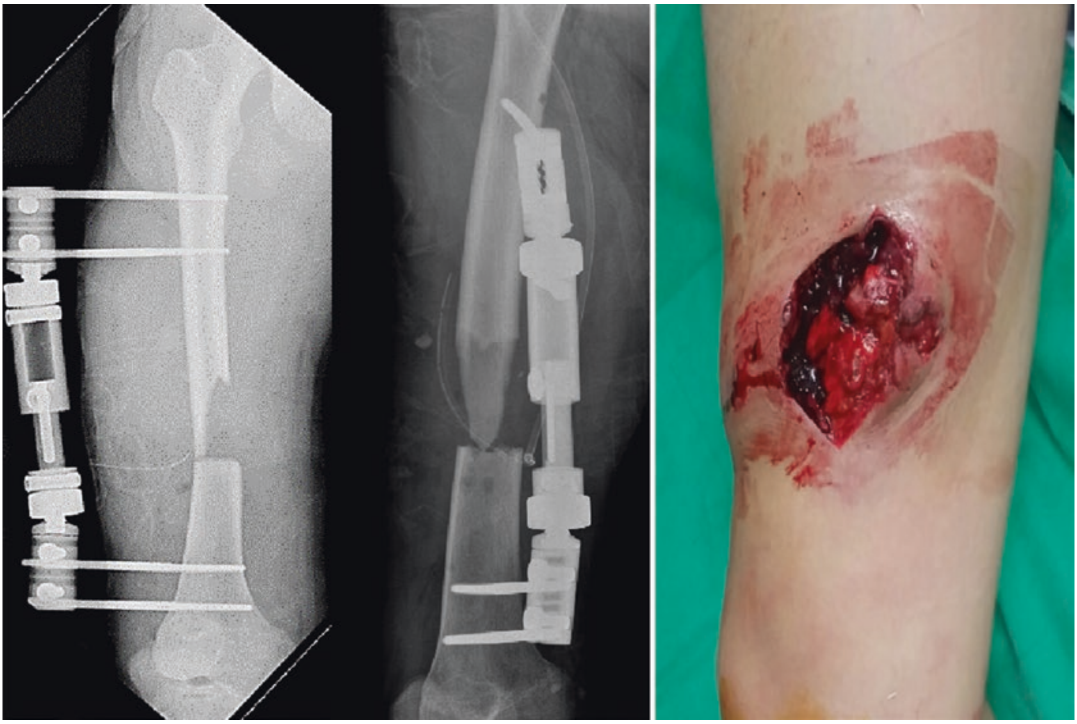

Fig. 7.4 Open femoral shaft fracture with bone loss. A 19-year-old male patient sustained a motorcycle accident. He suffered from the Gustilo-Anderson type IIIb open femoral shaft fracture. The middle fragment was not retrieved and missed when he was transferred to our institute after external fixation at the local hospital. Since we fixed the fractured femur in the shortened state, the open wound could be closed primarily without tension

Although Richardson et al. reported that the patients treated with magnetic lengthening nails underwent fewer surgeries (3.1 versus 2.1) and had a shorter time to union (136.7 versus 100.2 days) compared to lengthening over a nail, it must be confined to the simple lengthening case in which the proximal and distal interlocking is possible from the first operation (See Chap. 11 for Limb Lengthening using Intramedullary Lengthening Nail) [24, 25]. I believe lengthening over a nail was the only solution for this patient (Figs. 7.7, 7.8, 7.9, 7.10, 7.11, 7.12, and 7.13). Moreover, the external fixator could compress the docking site, which facilitated the bone union. Otherwise, an additional surgery such as autoiliac bone graft and osteosynthesis would have been necessary. Davda et al. also reported the result of the "rail and nail" technique using a retrograde femoral nail and external fixator to treat atrophic femoral nonunion. They concluded that this small retrospective study showed encouraging results for a combined technique, enabling compression of the femoral osteotomy, alignment, and controlled lengthening [11]. Removal of the fixator and proximal locking of the nail reduces the risk of complications and stabilizes the femur with the maximum working length of the nail in this case. A retrograde femoral nail was not applicable to our patient because of high-grade knee joint stiffness. We had no choice but to perform antegrade femoral nailing with its proximal end protruding to the buttock until the end of the femoral lengthening. It is well depicted in Fig. 7.10 (white arrow) [22, 26, 27].

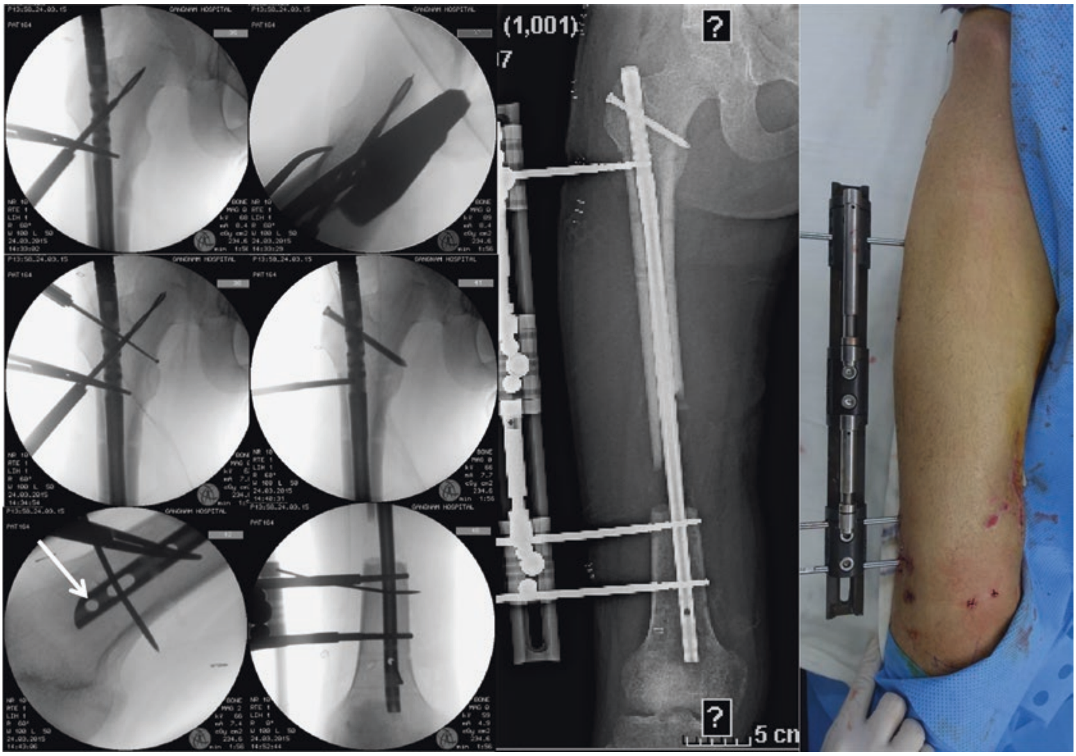

Fig. 7.5 Intraoperative findings of a nail plus external fixator application. We removed the preexisting external fixator and performed IM nailing with a slight distraction at the fracture site. The hole for the proximal reconstruction screw was used to assist in determining the anteversion of the femur. The drill bit was located in the center of the neck in the lateral view. In the distal part of the nail, the posterior aspects of both femoral condyles were overlapped while the distal interlocking hole was circular (white arrow). So, we could use the inherent anteversion of the nail, namely 15°, in this ZNN antegrade femoral nail (See Chap. 4). External fixator's pins were located in the posterior aspect of the nail in the distal fragment. The femur was lengthened until it matched the intact left femur using the monorail type external fixator

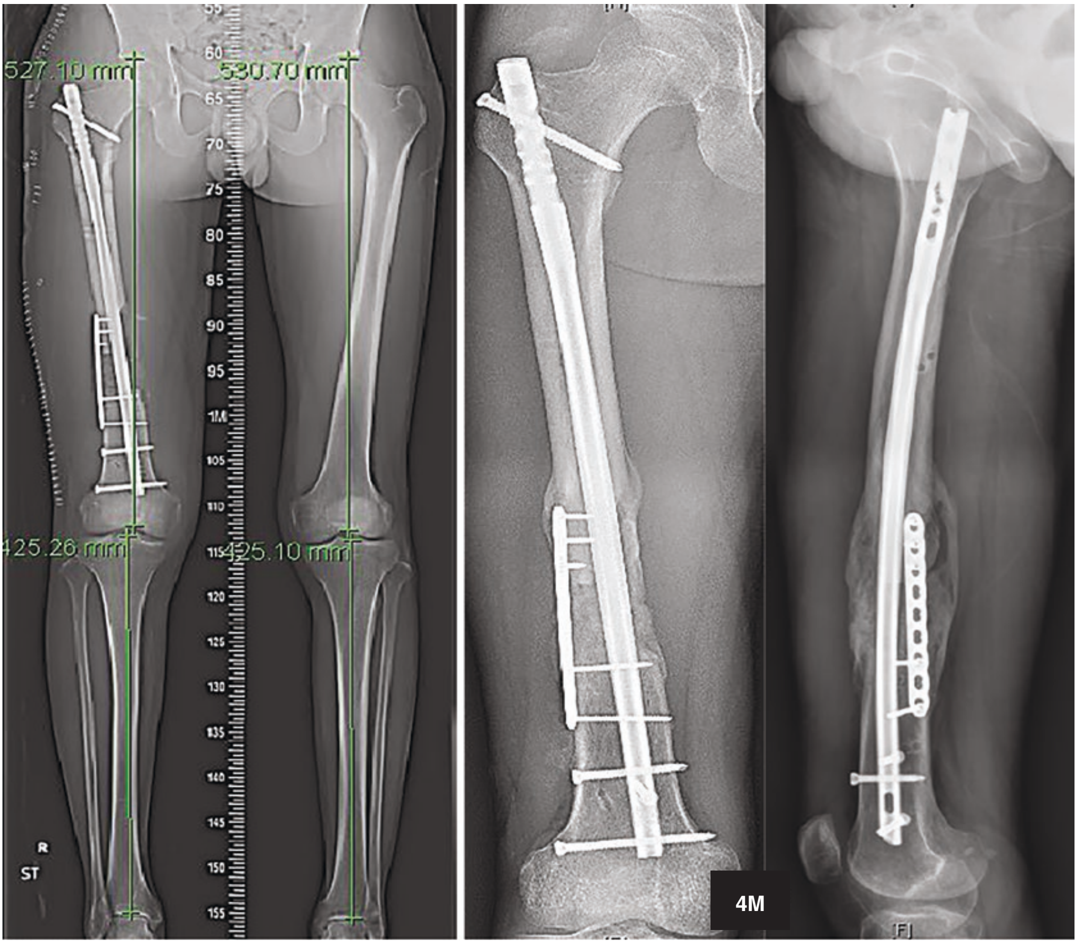

Fig. 7.6 A scannogram after bone graft and the radiograms at the final follow-up. Lengthening of the external fixator was stopped when the injured right femur got the normal length. The external fixator was removed after insertion of one Steinmann pin at the AP distal interlocking hole to prevent collapse at the defect at first. After distal interlocking, autoiliac bone graft and augmentative plate fixation were performed. Bone union was obtained 4 months after the operation. Augmentative plate fixation is at the surgeon's discretion

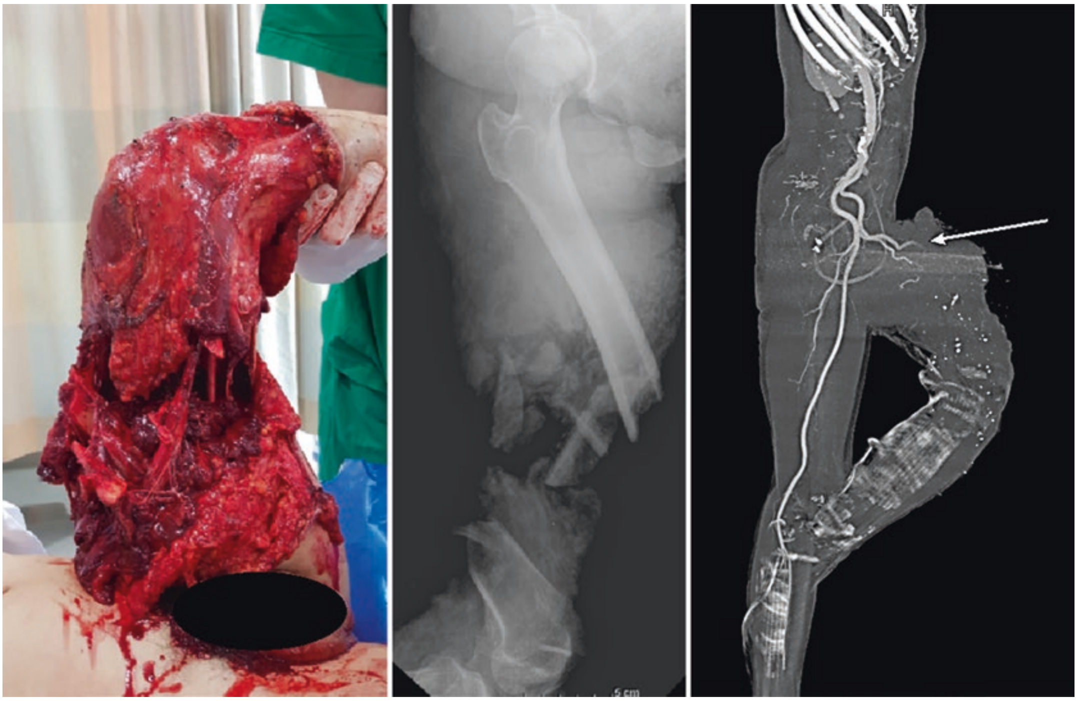

Fig. 7.7 Severe open type IIIc femoral shaft fracture. A 56-year-old male patient sustained Gustilo-Anderson type IIIc open fracture after machinery injury. His left thigh was crushed when it was pinched by the rotating arm of the parking elevator. The left photo was taken at the time of arrival at the emergency room. Only a narrow skin bridge and the sciatic nerve were preserved. After simple irrigation and dressing, radiography and CT-angiography were taken because there was no circulation distal to the wound. Tremendous comminution was noted in the distal femur with significant loss of bone. The femoral artery and vein were severed at the proximal end of the wound (white arrow)

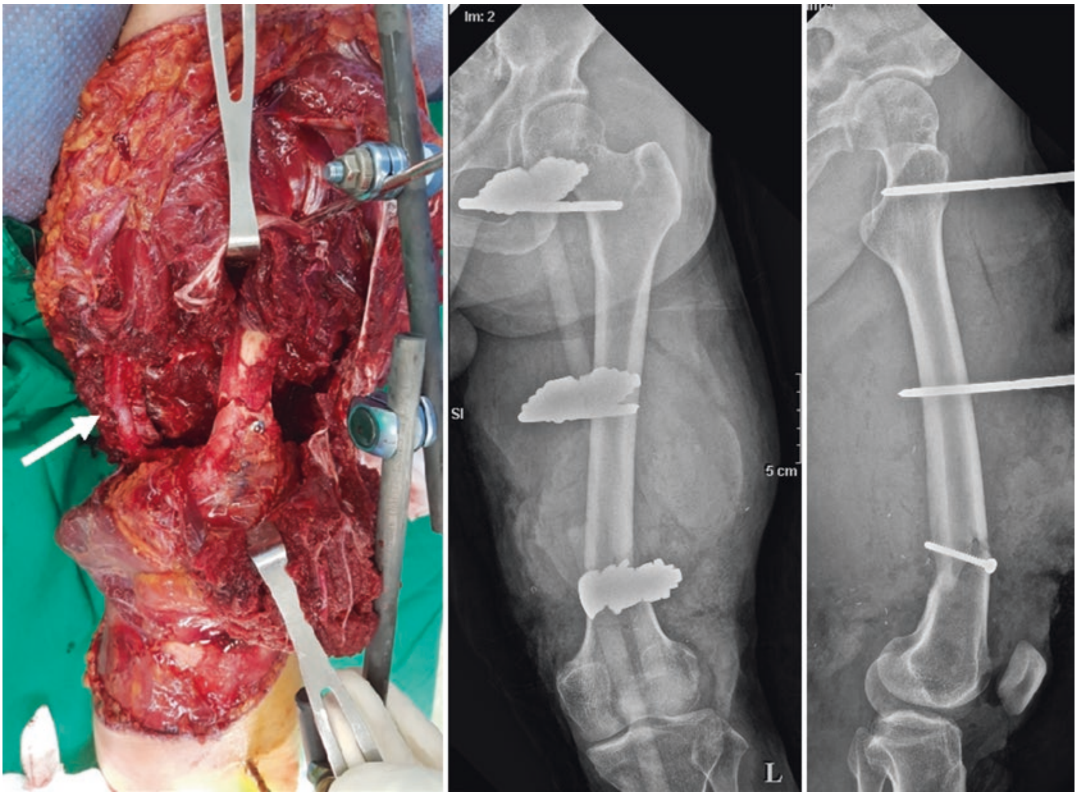

Fig. 7.8 Intraoperative findings and postoperative radiograms. Spanning external fixation and one cortical screw fixation were performed to stabilize the leg. Then the repair of the femoral artery and vein followed. Due to the shortening of the femur, the damaged vessels could be debrided and repaired in the end-to-end anastomosis method (white arrow). Valgus malalignment was noted at the fracture site, but the primary purpose of the screw fixation was augmentation of the spanning external fixation because its working length was long

Fig. 7.9 Soft tissue condition. The ruptured muscles were sutured loosely, and the negative pressure dressing was performed. The split-thickness skin graft using crushed skin on the lateral thigh failed to survive. Two months after the accident, the wound was ready for skin graft (middle) and successfully healed 3 weeks after the skin graft (right)

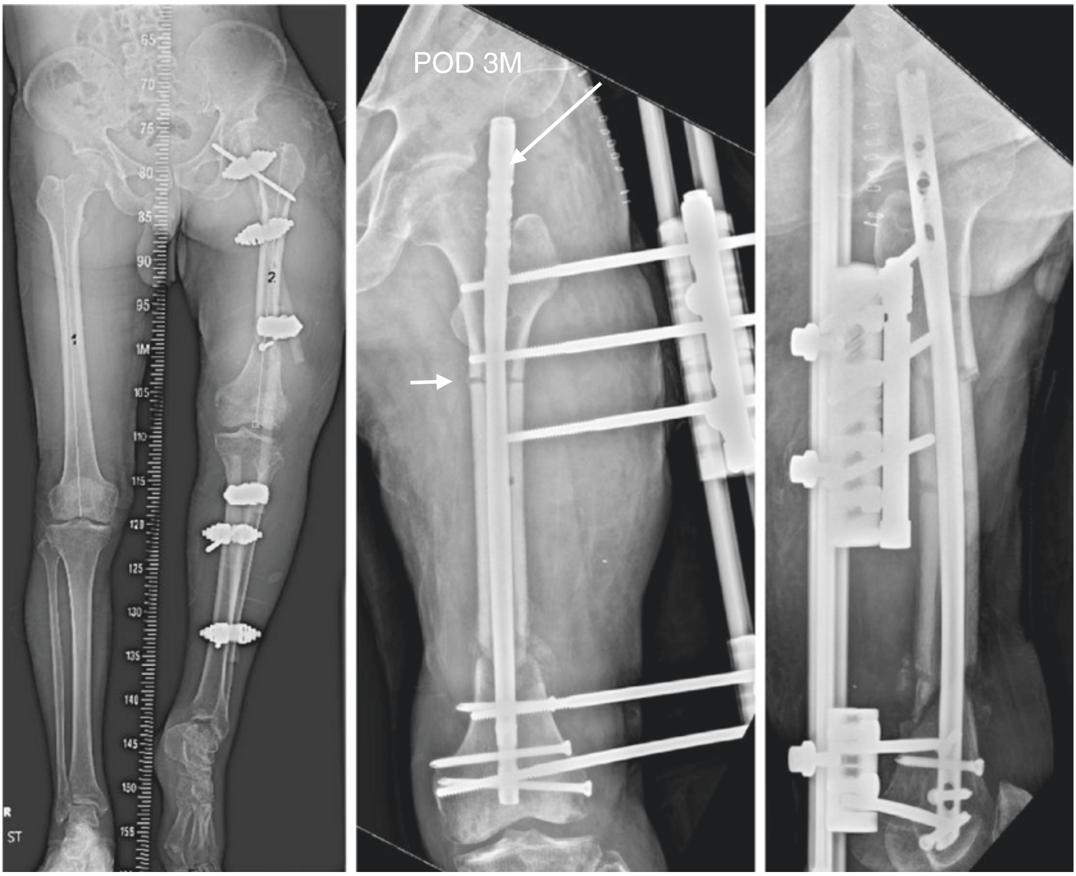

Fig. 7.10 Reconstruction for a short femur and a delayed union. Reconstruction of the femur was attempted 3 months after the accident. The spanning external fixator pin at the wound site was removed a week before the operation. Then, the left leg was kept under traction using an external fixator (tibial side) as a skeletal pin holder. The scannogram revealed 7 cm shortening of the left femur. The osteotomy was performed at the subtrochanteric area using a Gigli saw (short arrow). A screw at the fracture site was removed and a nail was inserted after reaming. Due to the short distal fragment, the proximal nail part was located outside of the femoral entry site (long arrow). A monorail type external fixator was applied at the posterior aspect of the nail for lengthening at the subtrochanteric area and compression at the original fracture site. Lengthening started 2 weeks after the osteotomy with a rhythm of 1 mm per day

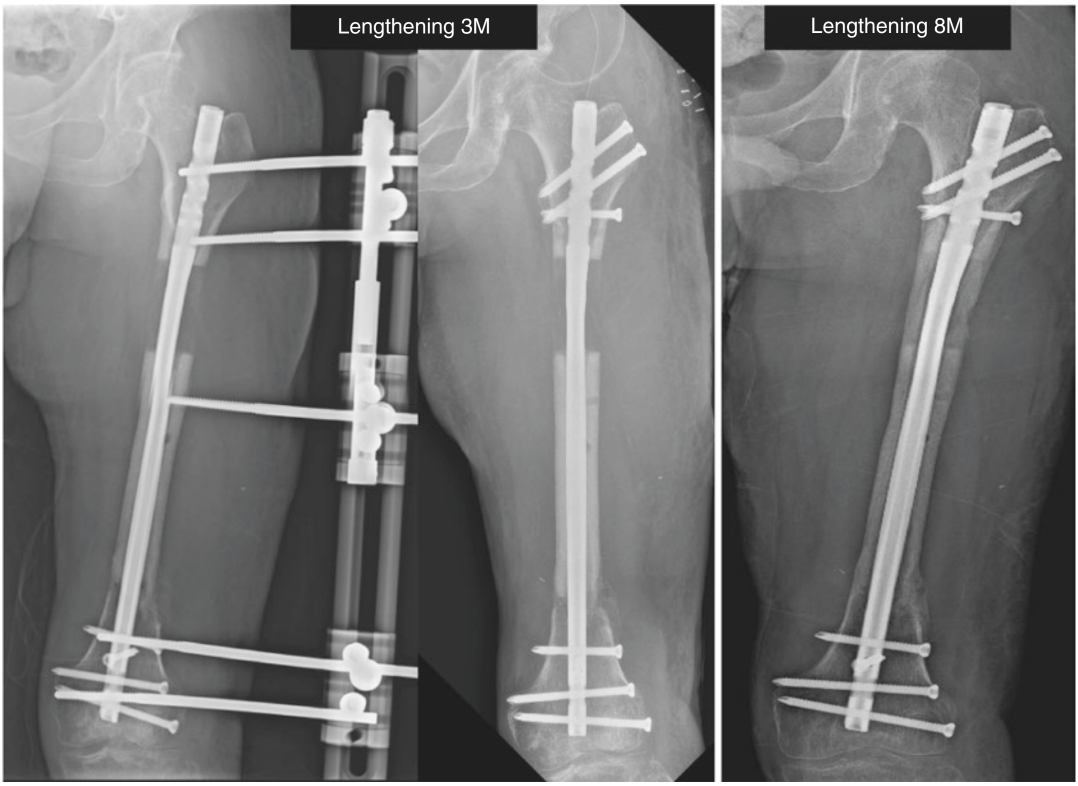

Fig. 7.11 The final stage of lengthening and the proximal interlocking of the femoral nail. Lengthening was completed after 3 months. The proximal targeting guide was assembled for proximal interlocking. After proximal interlocking, the external fixator was removed. Consolidation at the lengthening site was obtained at 8 months. The original fracture site (at the distal femoral shaft) healed during the femoral lengthening. Due to stiffness of the knee joint, Judet quadricepsplasty was performed at this stage of rehabilitation

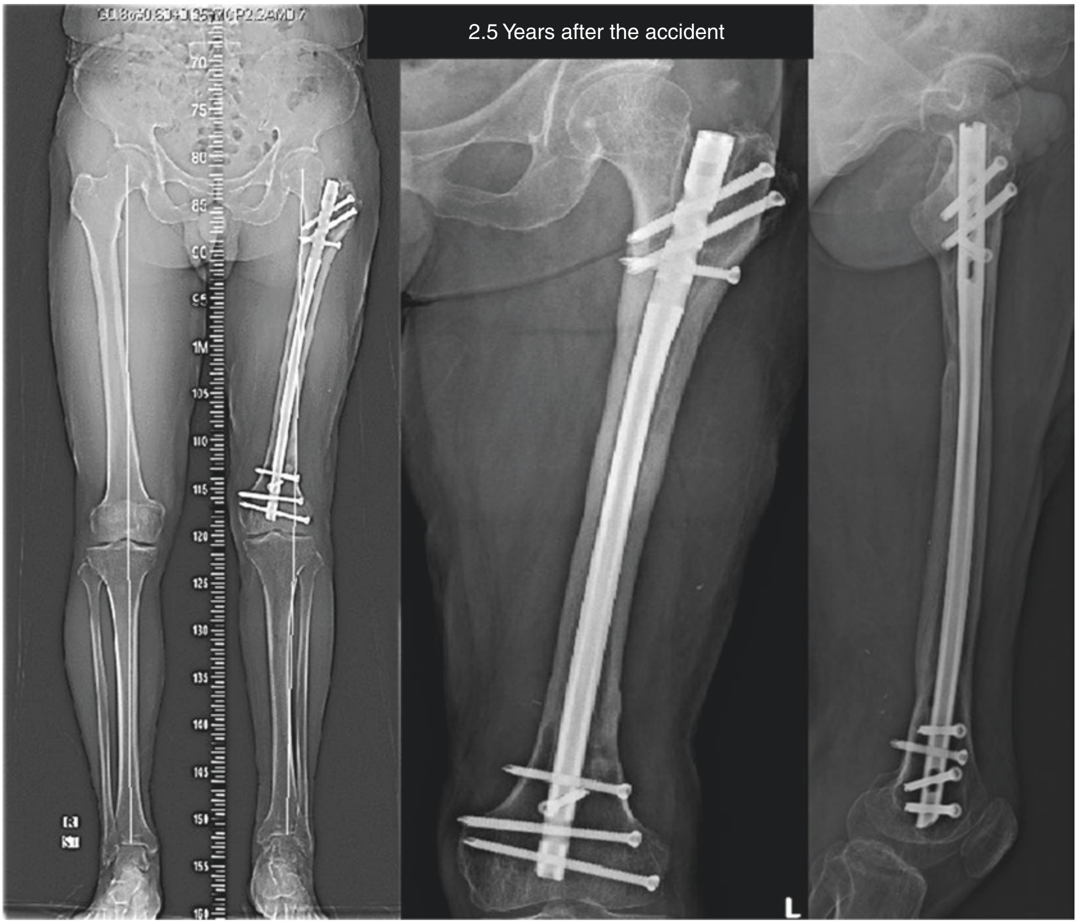

Fig. 7.12 Scannogram and radiogram 2.5 years after the accident. The femoral length was restored, but slight valgus deformity was noted at the fracture site. Achilles tendon lengthening was performed for the equinus deformity of the ankle, which was developed due to sciatic nerve injury. The tibial nerve was fully recovered. However, the peroneal nerve did not recover for 2.5 years

Fig. 7.13 The patient could walk without a walking aid and return to his job 2 years after the injury

7.3 IM Nailing with Bone Defect Filled with Bone Cement (Masquelet Technique)

Masquelet technique is a two-stage surgical procedure to reconstruct segmental bone defects. First performed by Dr. Masquelet in the mid-1980s, this technique has shown great promise to revolutionize critical-sized bone defect repair and has several advantages over its alternative, distraction osteogenesis. The autologous foreign-body membrane created during the first stage by the immune response to a polymethyl methacrylate bone cement spacer is critical to supporting the morselized bone graft implanted in the second stage (Fig. 7.14, 7.15, and 7.16). However, the biological and/or physical mechanisms by which the membrane supports graft to the bone union are unclear [28].

This poor lady sustained a simple spiral fracture after a slip down 8 years ago. Failure of the first treatment (IM nailing) caused a long-standing nonunion and segmental bone necrosis, probably due to repeated operations at the nonunion site (Fig. 7.14). Unexpected milky discharge from the wound let us abandon the initial plan of plate osteosynthesis and shift to external fixation and Masquelet technique. Fortunately, bone necrosis was not associated with infection and the second operation successfully obtained bone union (Figs. 7.15 and 7.16). Infection after plate osteosynthesis causes multiple problems such as nonunion associated with bone necrosis, sinus tract formation, and stiffness of adjacent joints due to the long-term use of an external fixator. Therefore, Masquelet technique is frequently used in the treatment of infected tibial nonunion.

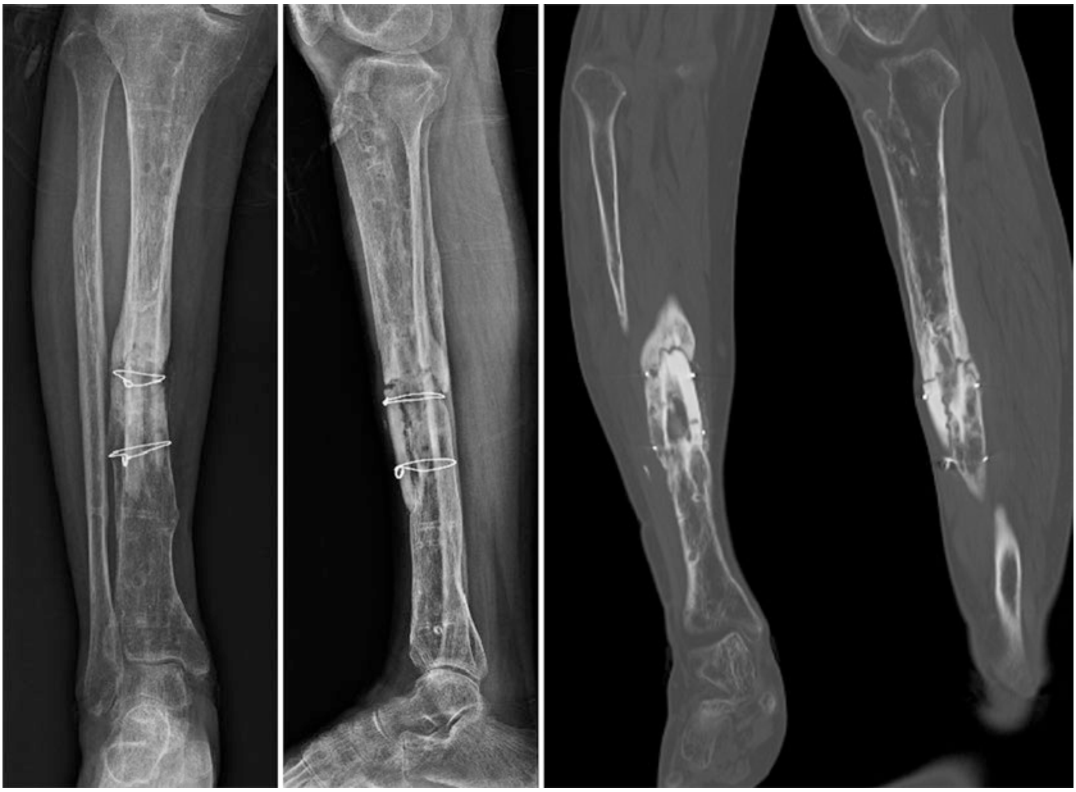

Fig. 7.14 A long-standing nonunion of the tibia with segmental bone necrosis. A 57-year-old female patient sustained a tibial shaft fracture after a slip down 8 years ago. She underwent tibial nailing, which resulted in nonunion. Then, the nail was removed, and plate osteosynthesis was performed with allo-fibular and autoiliac bone grafts. She experienced plate failure and nonunion again. Then, she underwent Ilizarov external fixation to treat the nonunion. After the removal of the external fixator, the pain developed again, so she visited our clinic for the treatment of an 8-year-old nonunion

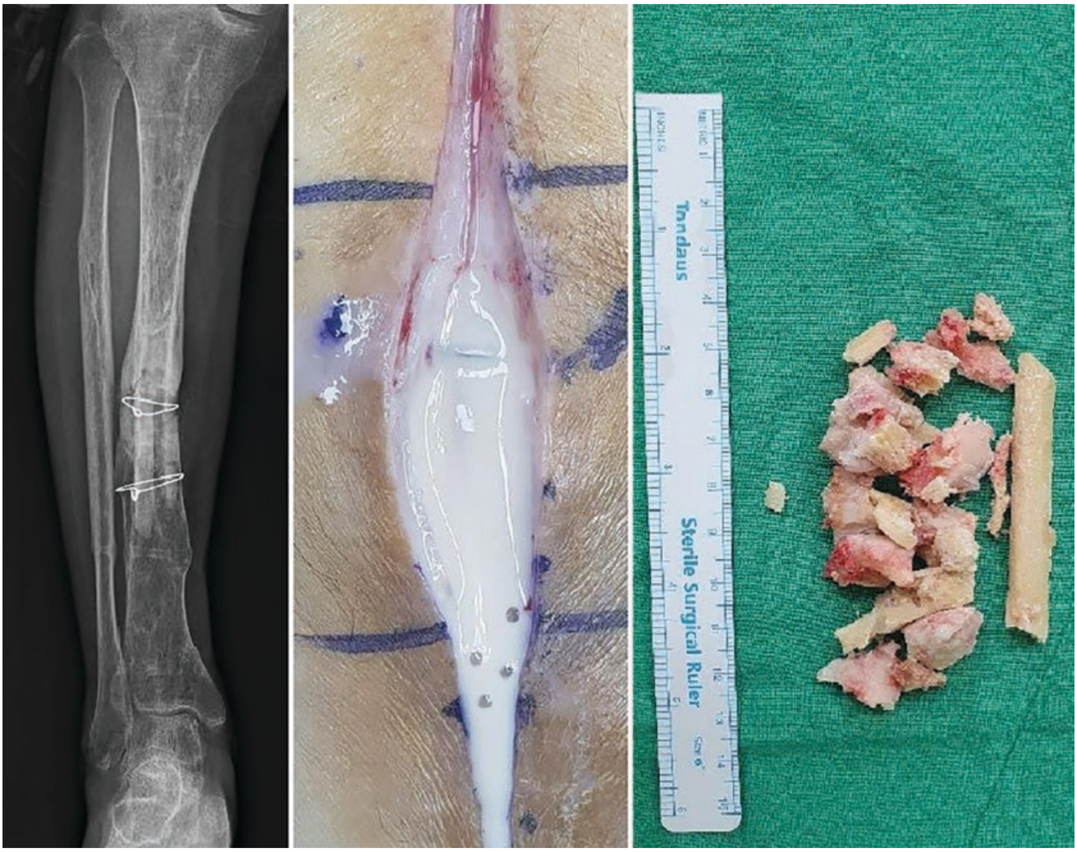

Fig. 7.15 Unexpected intraoperative finding. We planned to treat this nonunion with a locking plate and autoiliac bone graft after resecting the necrotic bone. However, a white milky discharge gushed out from the wound immediately after the skin incision. We recognized that the underlining bone was all necrotic. We debrided the necrotic bone and embedded a bone cement in the defect. Then, we applied an external fixator in a rectangular shape. Bacterial culture was negative

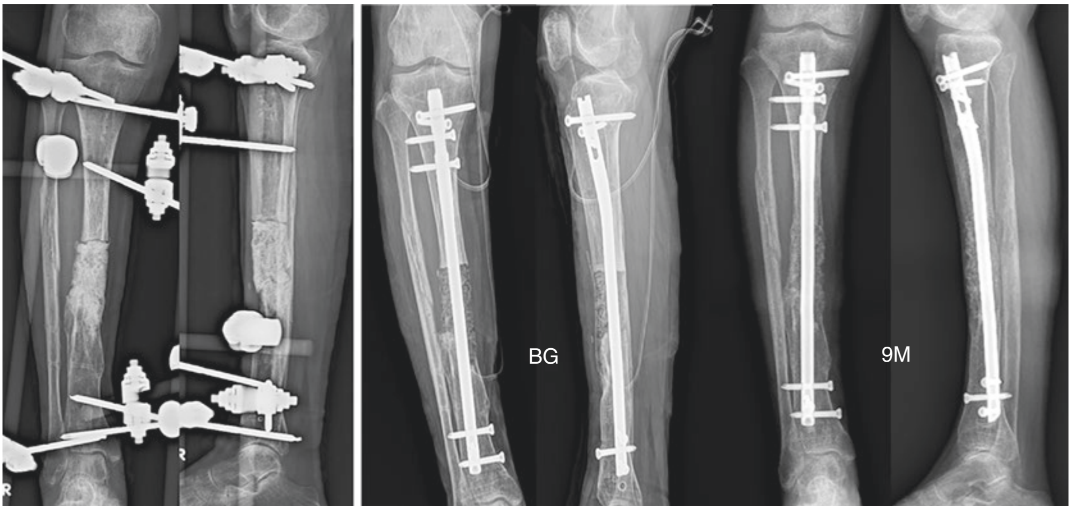

Fig. 7.16 Masquelet technique. Six weeks after the debridement and cement impregnation, the second operation was performed. It consisted of (1) removal of the external fixator, (2) removal of bone cement, (3) IM nailing, and (4) autoiliac bone within the biologic membrane. The allograft (bone chips) was added to increase the volume of the graft. Bone union was obtained 9 months after the second operation

7.4 Internal Bone Transport Using a Monorail Type External Fixation System

IM nailing is not the only way to treat the open femoral shaft fracture with a bone defect. Internal transport using various types of external fixators makes it possible to overcome a significant bone defect in the femoral shaft. I prefer the monorail type external fixator in the femur due to its simplicity and comfort (Figs. 7.17 and 7.18). I used to save the Ilizarov external fixator for tibial lengthening.

This poor male patient underwent eight operations to no avail before coming to our hospital. Our strategy was straight: removal of the necrotic bone, overcoming the defect and shortening of the femur, and treating nonunion. Due to a delay in new bone formation (osteogenesis) at the lengthening site, the patient had to keep the external fixator for 10 months. The docking site was grafted with the autoiliac bone and fixed with a small plate. Even though Laubscher et al. reported that femoral lengthening with the Precice femoral nail achieved excellent functional results with fewer complications and greater patient satisfaction when compared with the external fixator system, the previous history of recurrent infections precluded the nailing option [17]. We used to nail the femur for internal transport or lengthening with the help of the external fixator because of the long holding time of the external fixator. The wavy lengthening portion is another drawback of the external fixator method. This patient wanted the safest way because he suffered a lot from the repeated operations due to infection after osteosynthesis in the previous hospital. The successful completion of the treatment brought joy to the patient and all the staff at our hospital.

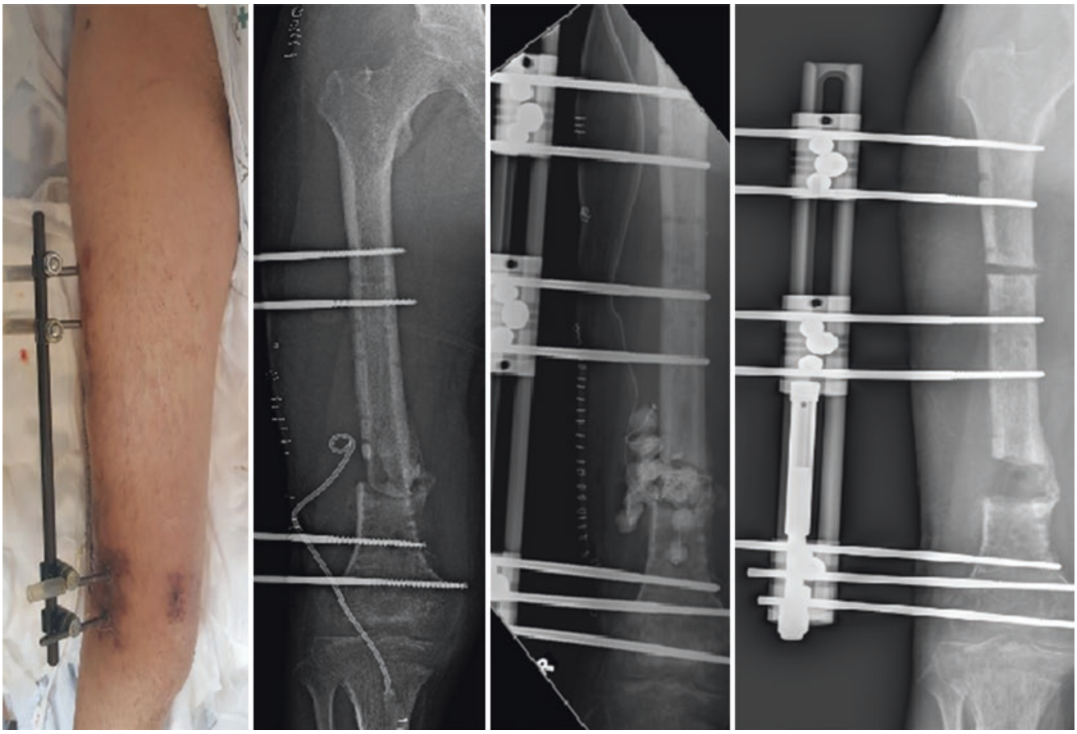

Fig. 7.17 Internal transport technique using a monorail type external fixator after segmental resection of the infected necrotic bone I. This 22-year-old male patient sustained a pedestrian injury. He underwent open reduction and plate osteosynthesis for the distal femoral shaft fracture at the local hospital. However, the hardware had to be removed due to infection, which did not respond to the repeated debridement and irrigation for 5 months. The external fixator was applied after the removal of the plate and screws. Then, he was transferred to our hospital for proper treatment of the infected nonunion and the severe stiffness of the knee joint. At first, we removed the preexisting external fixator and explored the wound to seek the necrotic bone. After removing the necrotic bone segment, we applied a monorail type external fixator to perform an internal transport and lengthening after osteotomy at the proximal femur

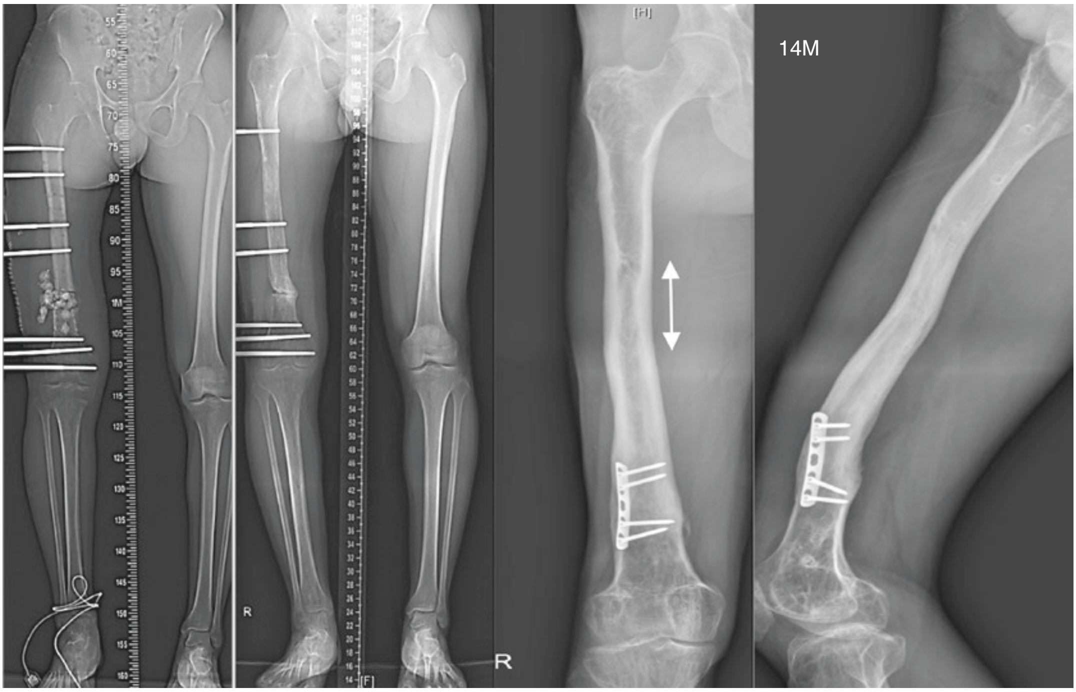

Fig. 7.18 Internal transport technique using a monorail type external fixator after segmental resection of the necrotic infected bone II. The bone defect was 3 cm in length. And the femur was shortened 2 cm (left). Internal transport and lengthening of the femur were performed until both femora got equal length in the scannogram. Infected femoral nonunion was healed after 14 month treatment which included femoral lengthening, docking site bone graft and osteosynthesis, and Judet quadricepsplasty. The final range of motion of the knee joint was 0–100°. The double-headed arrow indicates the lengthened portion

7.5 Combination of the External Fixator and Plate Osteosynthesis

The external fixator is an essential instrument in treating an open femoral fracture. However, the stability of the femoral uniaxial external fixator is not as good as that of the tibial external fixator. To enhance the initial stability, I prefer fixation of the main fragments with a cortical screw or a small plate after shortening, as shown in Fig. 7.8. Let us review another open distal femoral fracture case (Figs. 7.19 and 7.20).

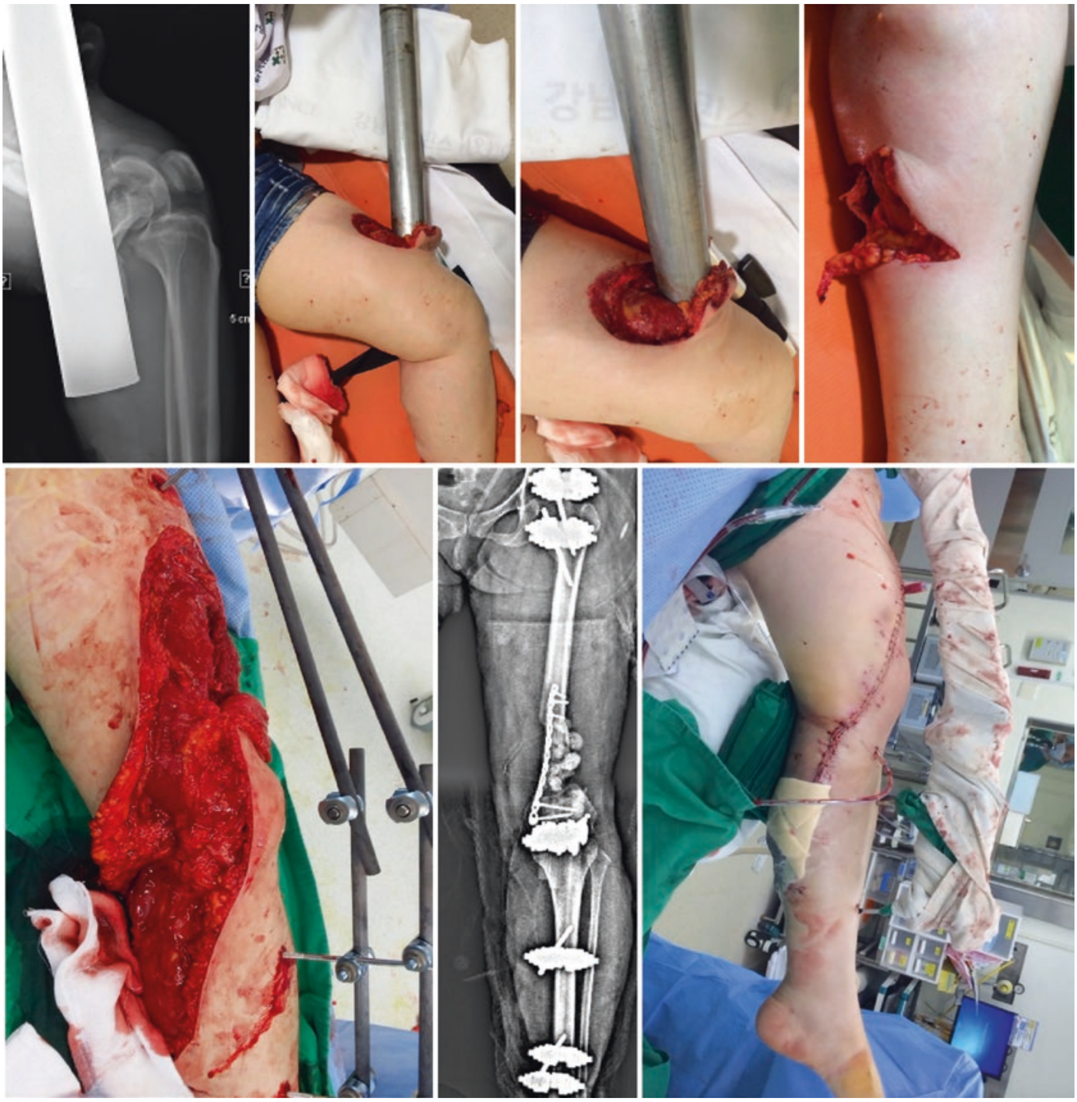

Fig. 7.19 A 40-year-old lady sustained an open supracondylar fracture of the left femur. A pipe of 2 m length fell from a four-story building construction site. It penetrated the anterior surface of her left thigh and smashed the supracondylar region of the left femur (upper left: The white rectangle in the radiography was the pipe penetrated into her lower limb.). Then, it passed through the popliteal fossa and exited the left calf (upper right). It seemed that the pipe end hit the ground and bounced back into the calf muscles. Circulation of the lower extremity was preserved, but the peroneal nerve injury was noted. The pipe was removed from the leg after general anesthesia in the operation room. After copious saline irrigation, a spanning external fixator was applied to stabilize the limb. The popliteal fossa was explored through a medial approach connecting the entry and exit wounds to check the integrity of the nerves and vessels. There was no gross injury in the neurovascular structure. Gross comminution and instability between the shaft and femoral condyle were noted. The wound was relatively clean, and there was no soil contamination. A temporary small bridging plate was applied on the imaginary medial supracondylar line to augment the stability of the external fixator. Antibiotic impregnated bone cement was inserted on the bone defect to control infection in the open fracture type IIIb. It was also used to induce the biologic membrane for later autogenic bone graft (Masquelet technique)

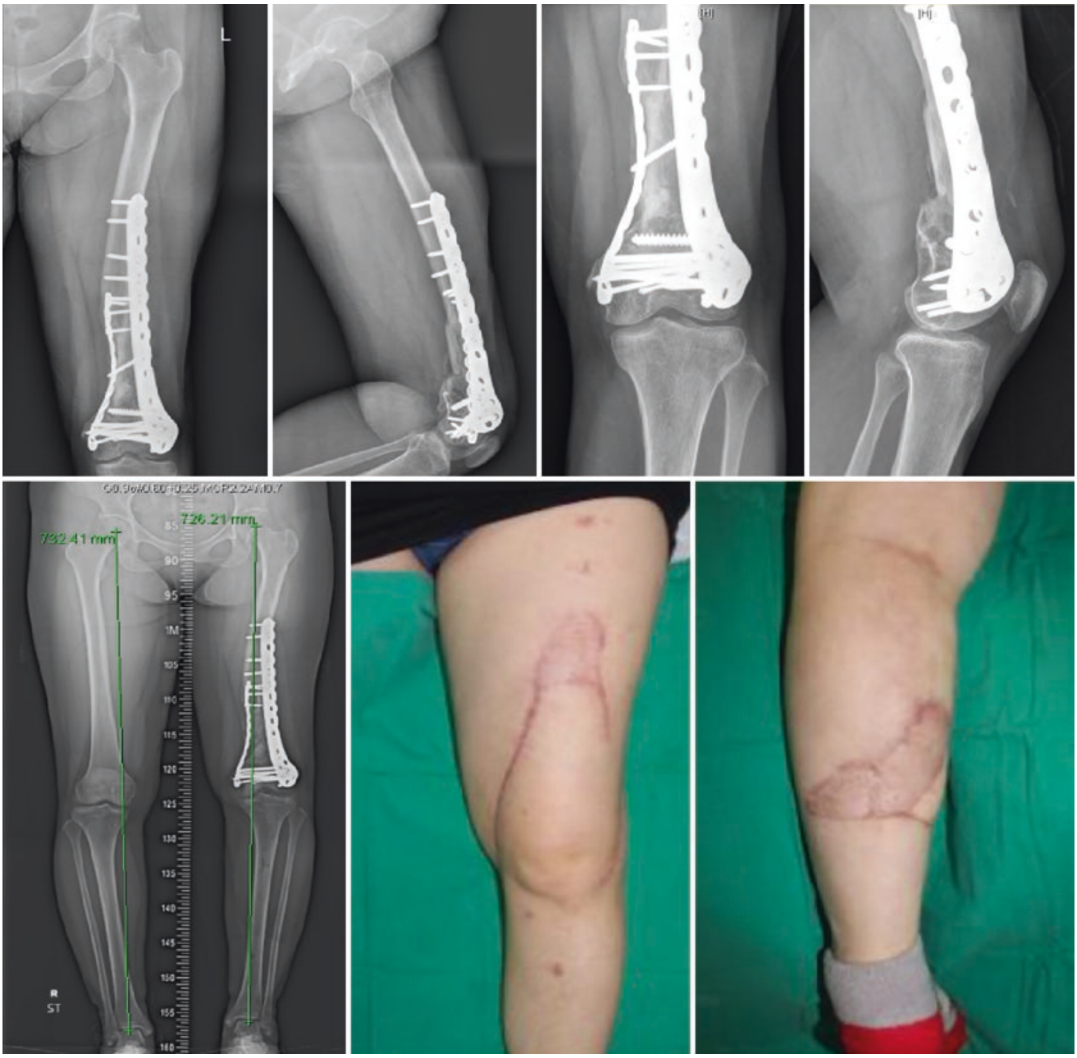

Fig. 7.20 The skin graft was performed at the entry and exit site while waiting for the biological membrane around the bone cement in the bone defect. After stabilizing the soft tissue condition, we performed plate osteosynthesis through a lateral approach using a long locking plate. Autoiliac bone graft was also added within the biologic membrane after removal of the bone cement. A scannogram of the lower extremity revealed 6 mm shortening in the left femur. A brisement of the left knee was performed to treat the stiffness. Final range of motion of the knee was 0–90°. Hyperextension of the condylar fragment resulted in limitation of knee flexion. The solid union was obtained 1 year after the accident

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8 Atypical Femoral Fracture (AFF)

In 2007, a group of surgeons from Singapore reported a case series of 13 patients who sustained a low-energy subtrochanteric fracture. Nine of them were under long-term alendronate therapy for osteoporosis. They suggested that prolonged suppression of bone remodeling with alendronate might be associated with a new form of insufficiency fracture of the femur (Fig. 8.1). Since then, many papers have been published regarding AFF [1–3].

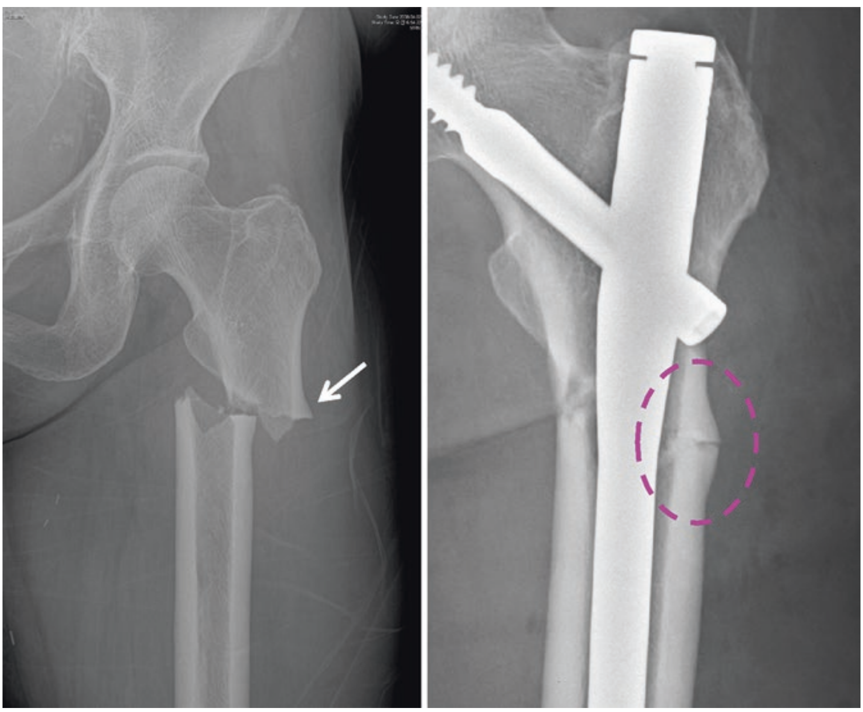

Fig. 8.1 A 60-year-old lady who underwent steroid and bisphosphonate therapy for asthma sustained a subtrochanteric fracture after a simple fall. A small periosteal beak at the lateral cortex (white arrow) was not recognized in the initial radiogram but was evident in the postoperative radiogram (circle). The fracture line is transverse in the lateral cortex and becomes oblique toward the medial cortex

K. H. Yang, *The Art of Intramedullary Nailing for Femoral Fracture*,
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8.1 Association with Bisphosphonate (BP)

BPs are anti-resorptive drugs prescribed to treat osteoporosis. They have a similar chemical structure with pyrophosphate and have a strong affinity to hydroxyapatite. So, once they are attached to the bone, half-lives become very long. BPs suppress the osteoclast function by blocking the mevalonate pathway when osteoclasts take BPs during bone resorption. BP eventually induces apoptosis of the osteoclast. Since BPs reduce physiologic bone remodeling and pathologic one, long-term use of BP might "freeze" the skeleton, allowing accumulation of microcracks over time, leading to fatigue fractures [3, 4].

A long-term intake of BP has been regarded as a major cause of atypical femoral fracture since its first report mentioned above. Wang et al. reported the adjusted hazard ratios of intertrochanteric/femoral neck fractures (osteoporotic fracture) and subtrochanteric/femoral shaft fractures, comparing highly compliant vs. less compliant group of BP intake. After 1 year of BP treatment, the risk of intertrochanteric/femoral neck fractures in the high compliance group became significantly lower than that in the low compliant group. It remained so for the rest of the treatment duration. In contrast, the hazard for subtrochanteric/femoral shaft fractures turned significantly higher after 2 years of treatment in the high compliance group and reached the highest risk at 4.06 in the 5th year [5].

Schilcher et al. estimated the relative and absolute risk of atypical fractures associated with BP use using a nationwide cohort analysis. The increase in absolute risk was 5 cases per 10,000 patient-years. After BP withdrawal, however, the risk of AFF diminished by 70% per year since the last use. In general, 10–15% of the AFF occur in naïve patients [4]. Bowing of the femur has been regarded as another cause of AFF in elderly people. The fracture usually occurs at the apex of the femoral bowing (Fig. 8.2) [6, 7]. Coxa vara seems

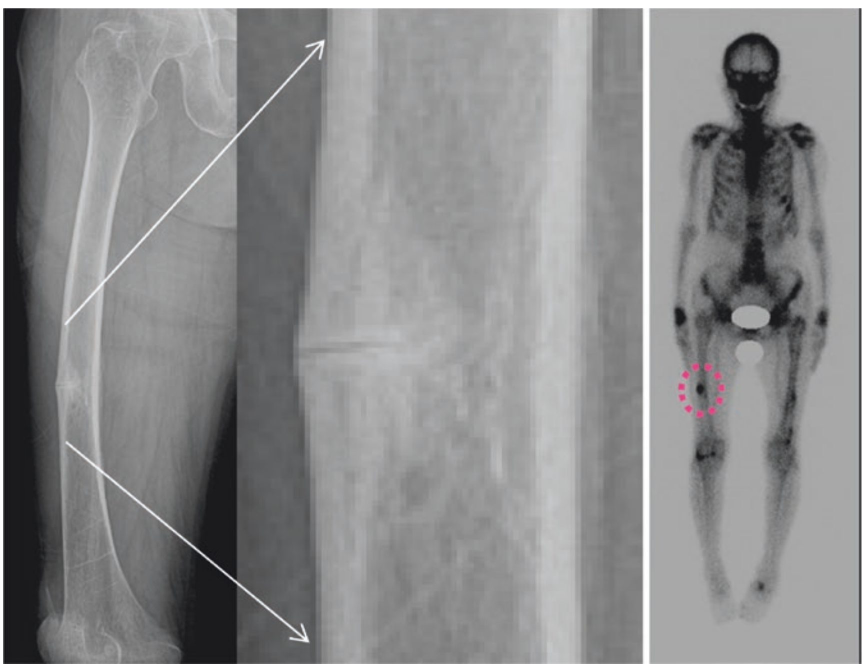


Fig. 8.2 AFF (the insufficiency type of femoral fracture) always starts from the lateral cortex, where the microcrack begins at the point. The stress concentrates on the apex of the curve from daily stress. A repeated long-standing cycle of microfracture and healing process results in bony sclerosis at the fracture ends with abundant endosteal callus as well as a periosteal beak. In a bone scan, ^{99m}Tc is attached to the bone-seeking material, usually methylene diphosphonate. Methylene diphosphonate has a similar chemical structure to BP. Therefore, we can speculate that keeping BP therapy in AFF enhances BP accumulation at the callus, which would aggravate the vicious cycle because the osteoclast is essential to remove sclerotic bone to bridge the gap with healing callus

to be another risk factor of AFF [8]. Whatever the causes of AFF, a transverse fracture line at the lateral cortex of the femur is the crucial feature of the AFF [9].

8.2 Definition of AFF by the American Society of Bone and Mineral Research (ASBMR) Task Force Team

In 2009, the American Society of Bone and Mineral Research (ASBMR) convened a multidisciplinary, international task force to develop a case definition so that subsequent studies could be reported on the same condition. Most cases reviewed were women who had received oral alendronate monotherapy, although the specific bisphosphonate was not provided in one-third of the cases. The median duration of BP therapy was 7 years. Approximately 70% of patients had a history of prodromal groin or thigh pain, 28% had bilateral fractures and bilateral radiographic abnormalities, and 26% had delayed healing. The second report was reported in 2013 [10, 11]. To satisfy the case definition of AFF, the fracture must be located along the femoral diaphysis from just distal to the lesser trochanter to just proximal to the supracondylar flare. In addition, at least four of five *Major Features* must be present (see below). None of the Minor Features is required but have sometimes been associated with these fractures. Fractures of the femoral neck, intertrochanteric fractures with spiral subtrochanteric extension, periprosthetic fractures, and pathological fractures associated with primary or metastatic bone tumors and miscellaneous bone diseases such as Paget's disease and fibrous dysplasia must be excluded. Plate fixation sometimes leads to the development of new insufficient fractures at the end of the plate. According to the definition of ASBMR, this peri-implant fracture is not an AFF. In that context, IM nailing is the treatment of choice in AFF because it covers the entire length of the femoral shaft. The nail should remain in the medullary canal. Otherwise, refracture may occur at the previous fracture site.

Major Features

(1) The fracture is associated with minimal or no trauma, as in a fall from a standing height or less.
(2) The fracture line originates at the lateral cortex and is substantially transverse in its orientation, although it may become oblique as it progresses medially across the femur
(3) Complete fractures extend through both cortices and may be associated with a medial spike; incomplete fractures involve only the lateral cortex
(4) The fracture is noncomminuted or minimally comminuted.
(5) Localized periosteal or endosteal thickening of the lateral cortex is present at the fracture site ("beaking" or "flaring").

Minor Features

(1) Generalized increase in cortical thickness of the femoral diaphysis.
(2) Unilateral or bilateral prodromal symptoms such as dull or aching pain in the groin or thigh
(3) Bilateral incomplete or complete femoral diaphysis fractures.
(4) Delayed fracture healing.

8.3 Location of AFF

A dichotomous distribution in AFF location has been reported: subtrochanteric fracture and shaft fracture. The patterns of distribution are different between the Western and Eastern countries. This difference may be linked to anatomical variations but also to cultural differences between the two populations that influence physical activity [12, 13]. We have also checked the fracture levels in 99 patients. To elucidate the effect of anterolateral bowing on the fracture height of AFFs, we separated the AFFs into two groups according to the presence of anterolateral femoral bowing (56 patients in the straight group and 43 patients in the bowing group) and analyzed the fracture height. In the bowing group, the estimated apex height was measured on a standard anterior-posterior radiograph. The reference line (the line drawn from the tip of the greater trochanter to the center of the femoral condyle) used to grade the femoral bowing was moved parallel in order to touch the most curved (concave) site of the medial femoral cortex. Then, a perpendicular line to the reference line was drawn at the most curved site. The lateral cortex point where this perpendicular line reached was defined as the estimated apex (Fig. 8.3) [7].

The average fracture height from the greater trochanter was significantly more proximal in the straight group than in the bowing group ($p < 0.001$) (Fig. 8.4). The neck-shaft angle was not significantly different between the groups. From the mechanical perspective, the estimated apex point is usually located at the most lateral part of the femoral shaft, where high tensile stress is generated during the gait cycle. Since an AFF is regarded as a type of insufficiency fracture, we speculate that the microcrack begins at the point where the stress concentrates on the apex of the curve from daily stress. In the straight group, 64% of AFFs occurred in the subtrochanteric area, where the highest tensile stress is generated during gait in normal limb alignment [13].

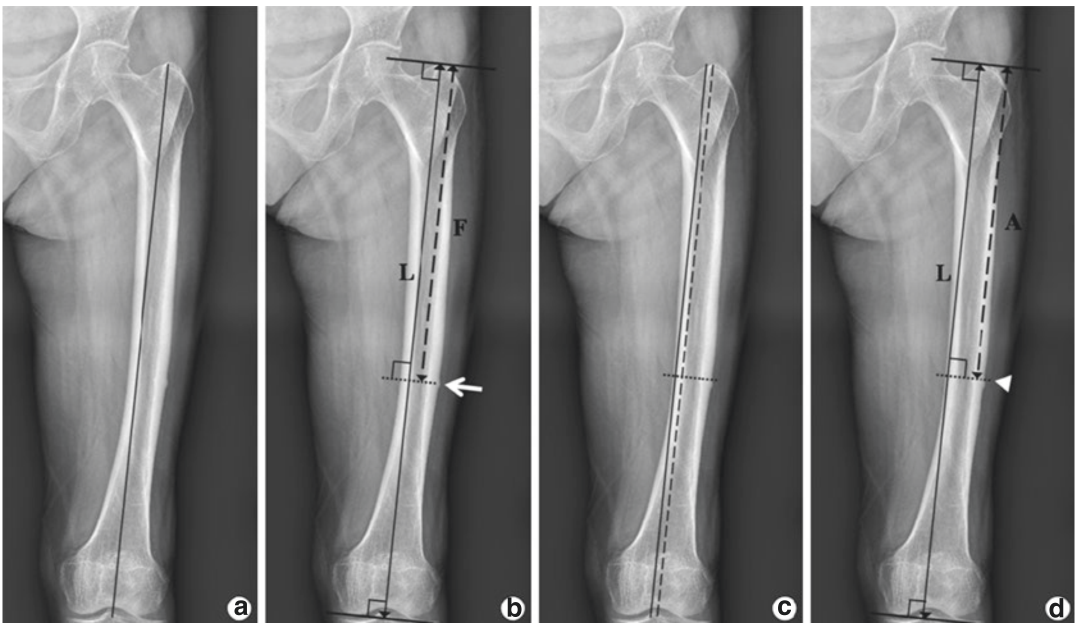


Fig. 8.3 Measurement of the fracture height (F) and estimated apex height (**A**) in the bowing femur group. Incomplete atypical femoral fracture with anterolateral bowing grade II. See Fig. 8.15: a new grading system for anterolateral femoral bowing for reference (**a**). The fracture height; *F* ratio (%) = *F*/the entire femoral length (L) and fracture site (arrow) (**b**). The reference line (dashed line) is moved medially to find the tangent point in the medial side of the medial femoral cortex (**c**). The arrowhead indicates the A, which is at the same level as the tangent point of the medial side. The estimated apex height; *A* ratio (%) = *A*/*L* (**d**) [7]

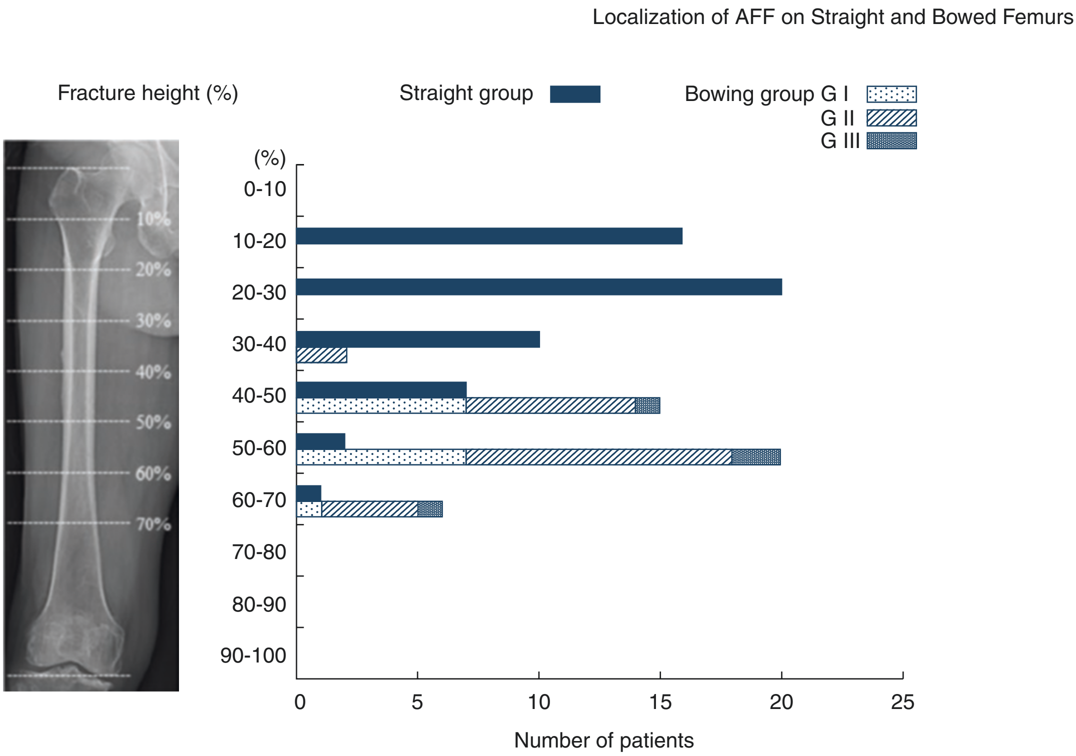


Fig. 8.4 Localization of AFFs on straight and bowed femurs. Subtrochanteric and proximal femoral shaft fractures occurred mainly in the straight femur group. In the bowing group, femoral shaft fractures occurred in the middle and distal one-third of the femoral shaft. The fracture usually occurs at the apex of the femoral bowing. The severity of anterolateral femoral bowing is not related to the fracture level but to the estimated apex [7]

8.4 Early Detection of Incomplete AFF

Early detection of AFF usually starts from the prodromal symptoms of the patient. The patient complains of dull thigh or groin pain which leads to the hip and thigh radiographic examination. When the suspicious lesion is detected on the lateral cortex of the femur, further examinations, such as bone scan and MRI, are required (Fig. 8.5) [14].

Dual-energy X-ray absorptiometry (DXA) is the most helpful tool in diagnosing osteoporosis. Osteoporosis treatment is recommended if the patient's T score is less than -2.5. BP therapy usually continues for several years because of the slow recovery of the skeletal system. Incidentally, we recognized a small periosteal or endosteal beak in the low–spatial-resolution hip images obtained with dual-energy x-ray absorptiometry (Figs. 8.6, 8.7 and 8.8) [15, 16].

Serial DXA images of 33 hips with AFF were assessed with ipsilateral DXA. Overall detection rates for DXA, prodromal symptoms, and DXA with prodromal symptoms were 61% (20 of 33), 42% (14 of 33), and 73% (24 of 33), respectively (Fig. 8.9). Overall detection rate comparisons showed that DXA with prodromal symptoms was superior to prodromal symptoms alone ($p = 0.0377$). In addition, the cumulative detection rate curve for DXA with prodromal symptoms was superior to that of prodromal symptoms alone ($p = 0.0018$). An extended femur DXA hip scan is advocated since about half of the AFF cases are developed in the femoral shaft.

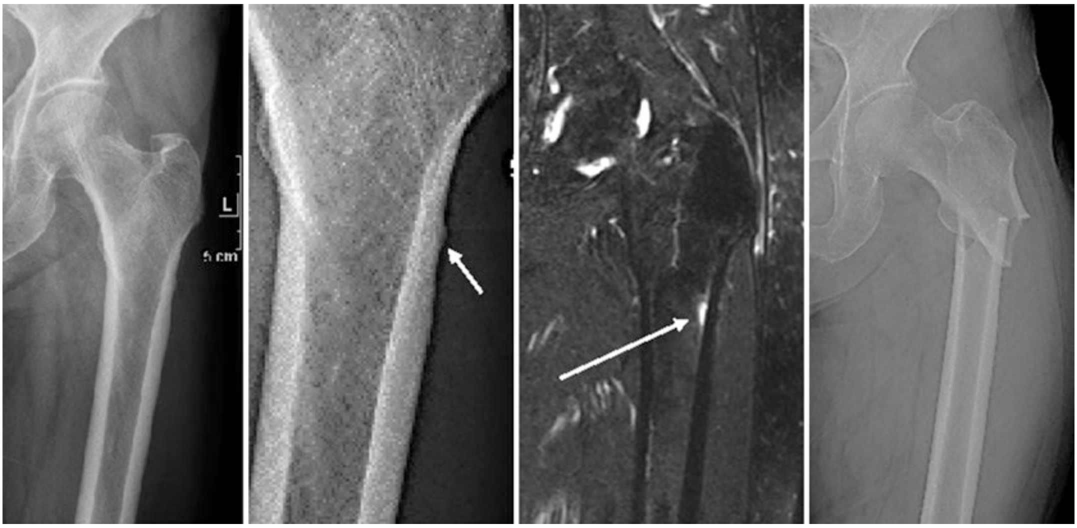


Fig. 8.5 A 63-year-old lady visited OPD for dull left thigh pain that lasted for 3 months. Minimal change on the lateral cortex on the subtrochanteric area (small white arrow) was noted. She underwent an MRI examination, which revealed bone marrow edema (long white arrow) around the minimal cortical change in the plain radiogram. She was treated with vitamin D and rest but sustained low-energy subtrochanteric AFF 3 months after detecting a pre-fracture lesion on the lateral cortex

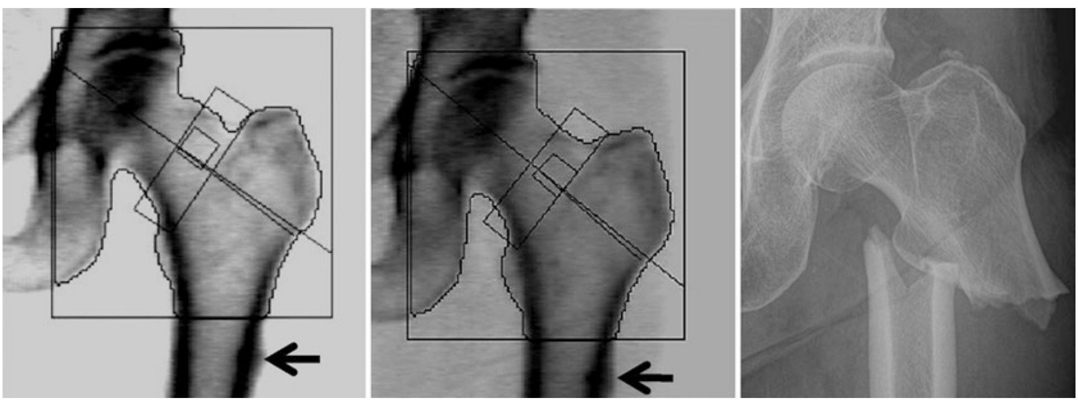


Fig. 8.6 A 69-year-old lady took BP for 5 years. The periosteal beaks (black arrows) were identified at the lateral cortex of the subtrochanteric area on the DXA hip images taken 19 (left) and 7 (middle) months before the complete fracture (right) developed. Periosteal flare is evident in the plain radiogram

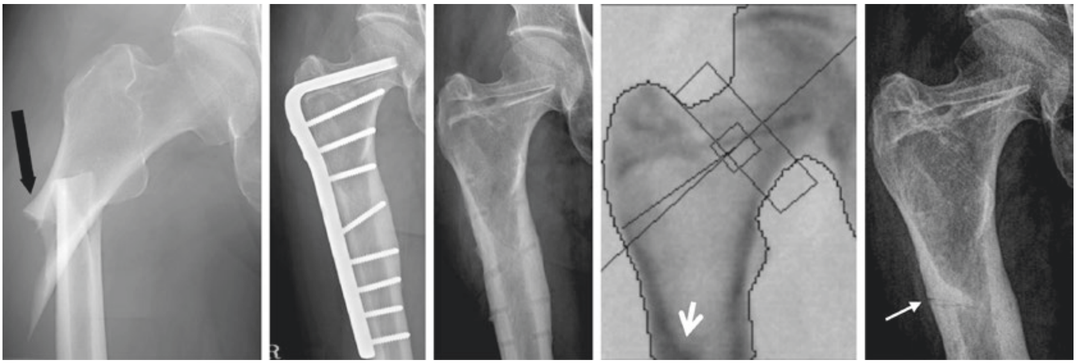


Fig. 8.7 A 57-year-old lady took BP for 10 years due to steroid therapy for control of asthma. Subtrochanteric fracture developed after a minor injury in 2005 when the AFF was not well recognized. The periosteal beak was ignored (black arrow). The subtrochanteric fracture was treated with 95° angled blade plate after open reduction. The fracture healed uneventfully, and the plate was removed 2 years after the accident. Two years after the plate removal, endosteal callus (thick white arrow) was detected in DXA hip image. The hip radiogram shows the crack started from the lateral cortex extending to the medullary canal with the endosteal callus (thin white arrow). AFF recurred at the same site

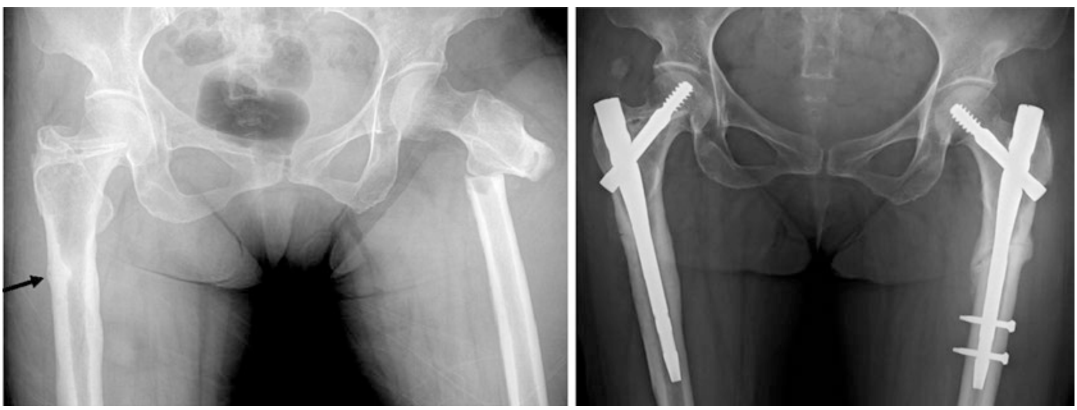


Fig. 8.8 A 62-year-old lady sustained subtrochanteric AFF on her left femur. She had a history of subtrochanteric AFF on the right femur 5 years ago (left). Closed reduction and internal fixation for the left displaced subtrochanteric AFF and prophylactic nailing for the right one (right image in Fig. 8.7 above) were performed. Healing was obtained 1 year after cephalomedullary nailing

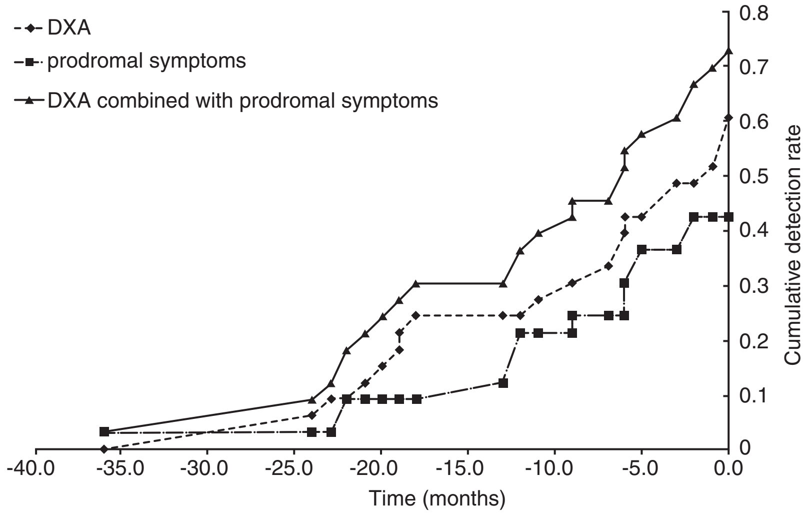


Fig. 8.9 Time-dependent graph shows a comparison of cumulative detection rate curves. The cumulative detection rate curve for DXA combined with the assessment of prodromal symptoms was statistically superior to that of prodromal symptoms alone ($p = 0.0377$) [15]

8.5 Treatment of Preclinical Cortical Lesions

From the low-quality evidence available, the recommendations of the ASBMR task force for medical management remain reasonable: discontinuation of BPs, adequate calcium and vitamin D, and consideration of parathyroid hormone (PTH; 20 μg daily subcutaneous injection) for those who appear not to heal on conservative therapy (Fig. 8.10). In the absence of a randomized, placebo-controlled trial, no definite conclusion can be reached regarding the efficacy of PTH treatment of patients with AFF. Prophylactic reconstruction nail fixation is recommended for incomplete fractures (with cortical lucency) accompanied by pain. If the patient has minimal pain, a trial of conservative therapy, in which weight-bearing is limited through the use of crutches or a walker, may be considered. However, if there is no symptomatic and radiographic improvement after 2–3 months of conservative therapy, prophylactic nail fixation should be strongly considered, because these patients may progress to a complete fracture [10, 11].

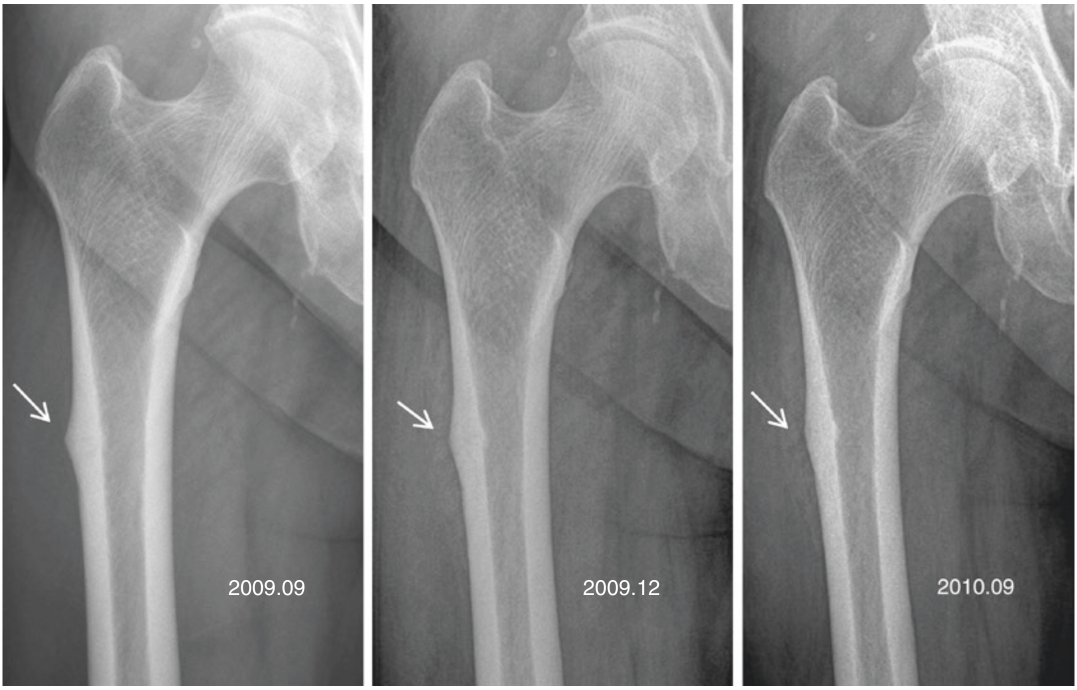
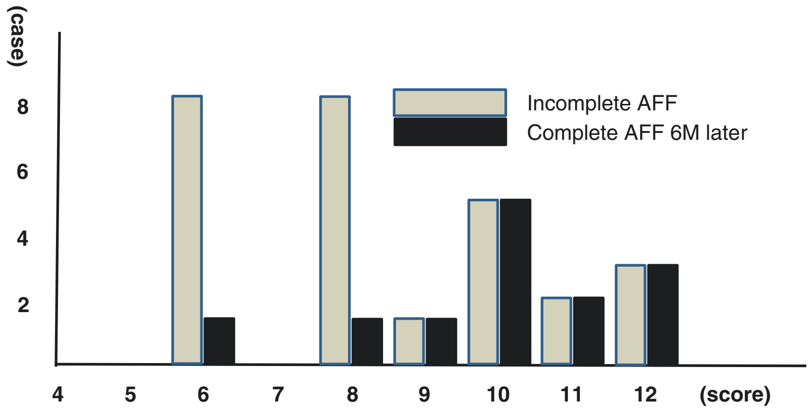


Fig. 8.10 Healing sequence of a successful PTH therapy. The sharp apex becomes blunter through 6 month PTH daily injection therapy and disappears after 1 year (arrows)

8.6 Risk Factors for Progression to Complete Fracture

Although most complete AFF cases have an asymptomatic contralateral femur at the initial presentation, it lacks clarity on its progression. Radiographic progression was noted in 18 patients (34%) during the mean follow-up of 48.9 months: 3 (12%) of 25 in grade 1 (with minor manifestations) and 15 (53.6%) of 28 in grade 2 (with major manifestations) ($p < 0.001$). The prevalence of radiographic progression was relatively high, even though the contralateral femur was initially asymptomatic and differed significantly according to the initial radiographic grade, namely the presence of major manifestation [17].

A weighted scoring system, including four identified risk factors (the site, severity of pain, status of the contralateral femur, and the extent of radiolucent line), was developed by a group of Korean surgeons. They concluded that incomplete AFF with scores less than 8 points could be treated conservatively, whereas lesions with more than 8 points require prophylactic fixation (Fig. 8.11) [18, 19].



Variable	1	2	3
Site	Others	Diaphyseal	Subtrochanteric
Pain	None	Mild	Functional
Contralateral	Complete	Incomplete	Intact
Radiolucent line	Focal change	<1/2	>1/2

Fig. 8.11 The black bars indicate the cases of progression to complete AFF from incomplete AFF after 6 months or later in each score. All patients over 9 points progress to complete AFF. Incomplete AFF with scores of less than 8 points can be treated conservatively, whereas lesions with more than 8 points require prophylactic fixation [19], (Courtesy of professor BW Min)

8.7 Surgical Treatment for Impending AFF (Prophylactic Nailing)

If the crack in the lateral cortex propagates to the medial cortex despite the conservative treatment for several months, prophylactic femoral nailing is indicated [9, 11, 20]. The result of prophylactic nailing is better than that of the nailing after a complete AFF fracture. AFF is notorious for delayed union and nonunion after surgical intervention in the complete fracture compared to the common femoral fracture. We must keep in mind three things before performing prophylactic nailing: (1) The ventilating hole in the distal one-third of the femur is necessary to decrease the medullary pressure during the reaming process due to the long distal medullary canal (distal to the femoral isthmus). Otherwise, pulmonary embolism of the medullary contents may develop (Fig. 8.12); (2) The hard endosteal callus must be removed to settle the nail in the proper position (Fig. 8.13); (3) In case of excessive anterolateral femoral bowing, several tips are necessary to avoid bursting of the femur during IM nailing.

Fig. 8.12 A ventilation hole was made before IM nailing to prevent pulmonary embolism of the medullary contents (white arrow). A proximal interlocking screw was inserted in the dynamic hole for load sharing. The femoral nail was inserted in external rotation to accommodate the anterolateral bowing of the femur (see Figs. 8.15, 8.16, 8.17, and 8.18)

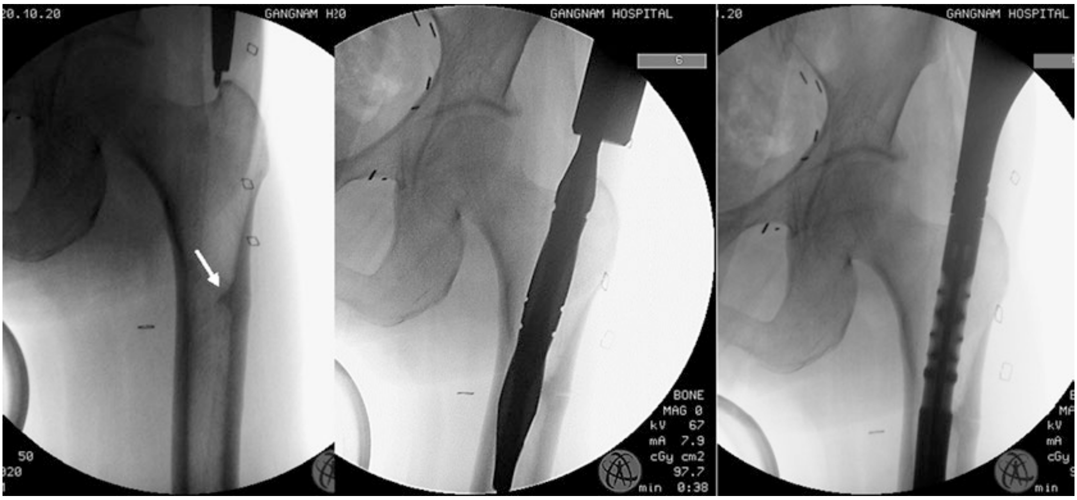


Fig. 8.13 Hard endosteal callus (white arrow) interrupts reaming process and must be removed by osteotome or oversized reamer. An endosteal callus pushes the trochanteric reamer to the medial cortex. Remnant of endosteal callus still pushes the nail to the medial side (right)

Three tips to overcome the mismatch between the nail and bowed femur are

1. Insertion of the contralateral nail (Off-label use): Use of a contralateral nail is a useful tip, but the off-label use of the nail is a significant burden for surgeons (Fig. 8.14) [20].
2. Lateral insertion (Limited success): Byun et al. reported that diaphyseal AFFs with grade 0–II bowing and < 20° anterior bowing were treated successfully by the shifted entry technique. However, postoperative malalignment was found in all cases of AFFs with severe bowing. Therefore, other techniques should be considered for AFFs with grade III bowing or ≥ 20° anterior bowing [21].
3. External rotation of the greater trochanter starting antegrade femoral nail. External rotation of the greater trochanter starting antegrade femoral nail converts the anterior bowing of the nail to lateral bowing so that the nail matches with the anterolateral femoral bowing (Figs. 8.15, 8.16, 8.17, and 8.18). The targeting guide must be rotated externally when the tip of the nail passes the apex of the femoral bowing. The curve's apex is well depicted in the new grading system [22, 23].

ZNN femoral nail system has a big advantage in nailing AFF with excessive anterolateral bowing. It equips nails with three different radii (inherent curvature) according to the length of the nail. The curvature is generally greater (small radius) with the smaller patients (Figs. 8.18 and 8.19).

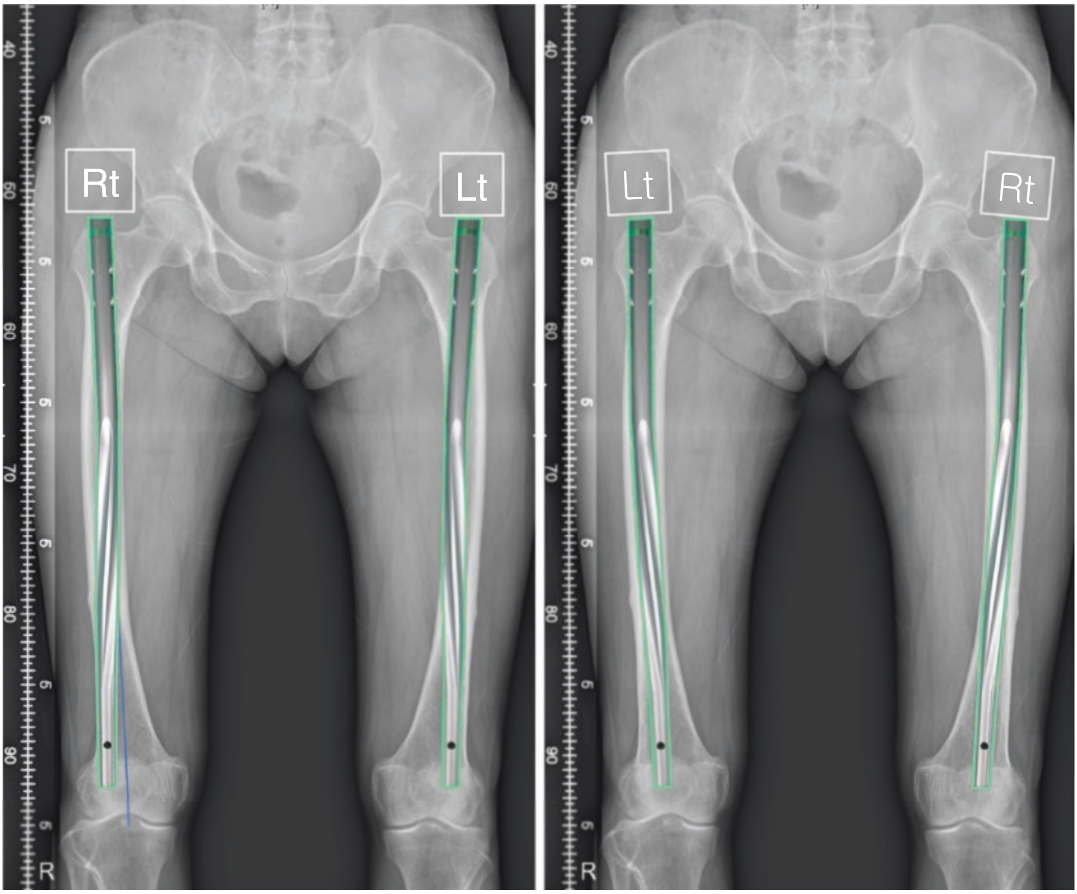


Fig. 8.14 The gross mismatch between the greater trochanter starting antegrade femoral nail and bowed femur (right). Off-label use of the contralateral nail overcomes the mismatch. However, it must be used with caution because the surgeon takes full responsibility when it fails to get good results

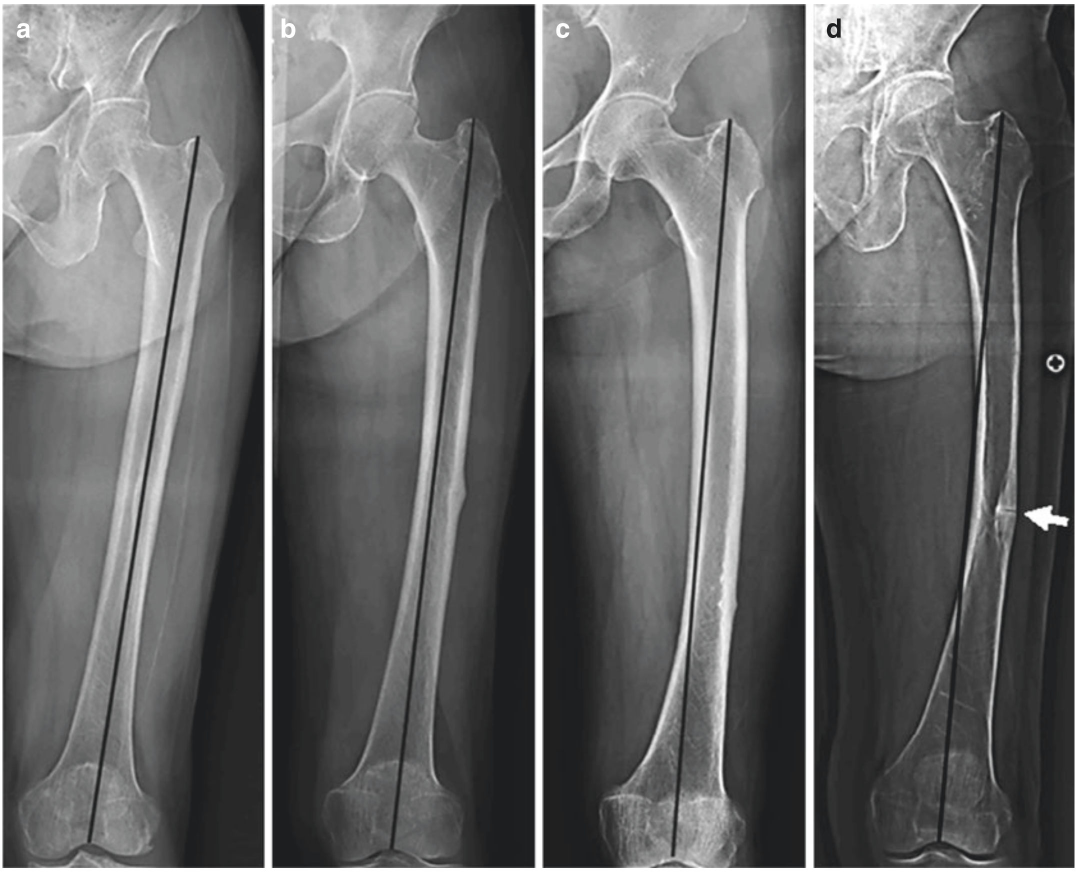


Fig. 8.15 A new grading system for anterolateral femoral bowing according to the position of the reference line at the apex of the curve of the bowed femur on a true anteroposterior radiograph. The reference line is drawn from the tip of the greater trochanter to the center of the intercondylar notch. (**a**) Grade 0 (straight) indicates that the reference line is located in the middle one-third of the medullary canal. (**b**) Grade I (mild) describes a reference line located in the medial one-third of the medullary canal. (**c**) Grade II (moderate) refers to a reference line that passes through the medial cortex. (**d**) Grade III (severe) describes a reference line that runs medial to the medial cortex. The arrow indicates the apex of the curvature. Excessive anterolateral bowing was defined as grade II or III [23]

Fig. 8.16 External rotation of the greater trochanter starting antegrade ZNN femoral nail converts the anterior bowing to lateral bowing so that the nail matches with the anterolateral femoral bowing [23]

Fig. 8.17 The patient was positioned on the fracture table in supine position and underwent IM nailing for left AFF with excessive anterolateral femoral bowing. The targeting guide was rotated externally while the nail tip passed the apex of the bowed femur. At the end of the procedure, the targeting guide was rotated internally about 30 degrees for distal interlocking [23]

Nail Length	Bow Radius
24 - 34 cm	1,270 mm
36 - 42 cm	1,400 mm
44 - 46 cm	1,520 mm

Fig. 8.18 The curvatures of the ZNN femoral nails vary depending on the length of the nails. The shorter the nail, the greater the curvature of the nail [24]. It is beneficial because many patients with excessive anterolateral femoral bowing have short femurs. Short bow radius (big curvature) helps the nail passage at the apex of the curve if the surgeon rotates the nail externally

Fig. 8.19 Incomplete AFF with Grade III bowing. Prophylactic nailing was necessary due to pain and propagation of the crack from the lateral cortex (arrow) (**a** and **b**). External rotation of the ZNN femoral nail made it possible to insert the nail in this extreme case. Distal interlocking from the posterolateral aspect of the femur is sometimes difficult due to the lateral supracondylar line (ridge) (**c**–**e**) [23]

8.8 Surgical Treatment (IM Nailing) for Complete AFF

IM Nailing for Complete Subtrochanteric AFF

The primary healing rate after cephalomedullary nailing of bisphosphonate-associated subtrochanteric AFF was 68.7%. The margin of errors is narrow compared to the common subtrochanteric femoral nailing. The cutoff points for neck–shaft angle, the difference in neck–shaft angle, and sagittal angulation were 125.6°, 4.4°, and 5.5°, respectively. That means only less than 5° of malalignment is acceptable in IM nailing for the subtrochanteric AFF [25–27]. So, a stricter strategy is necessary for subtrochanteric AFF. I have experienced that the higher the fracture, the more challenging it is to reduce the fracture in the acceptable alignment (Figs. 8.20, 8.21, and 8.22). Thus, I strongly recommend prophylactic nailing in the case of high subtrochanteric fracture (just below the lesser trochanter).

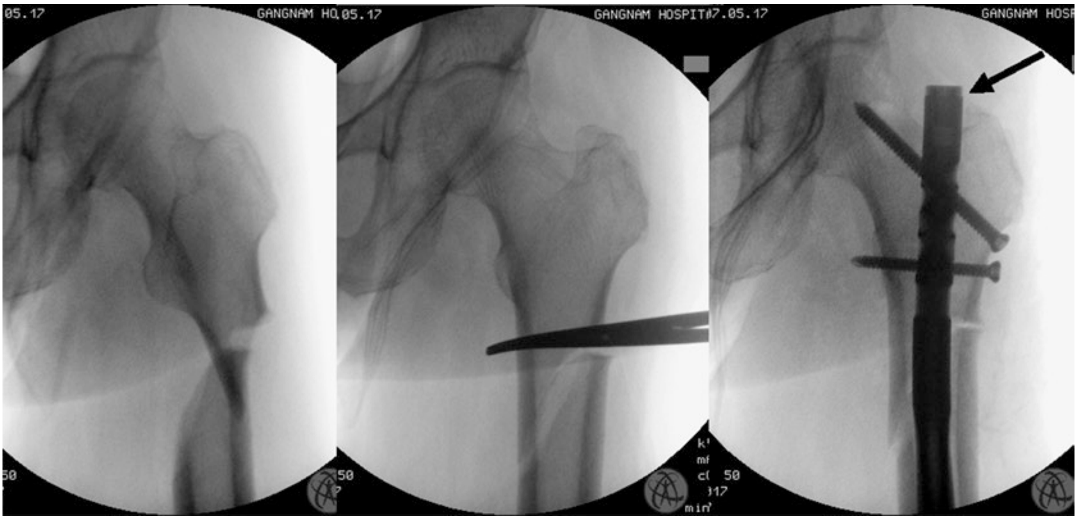


Fig. 8.20 IM nailing of subtrochanteric AFF is not difficult if the long-curved forceps inserted in the proximal fragment from the lateral thigh can reduce the typical flexion, external rotation, and abduction deformity of the proximal fragment as in this case. The complex deformities are reduced with ease using a long tonsil clamp. The entry point must be made on the medial inner slope of the greater trochanter to avoid varus malalignment (black arrow)

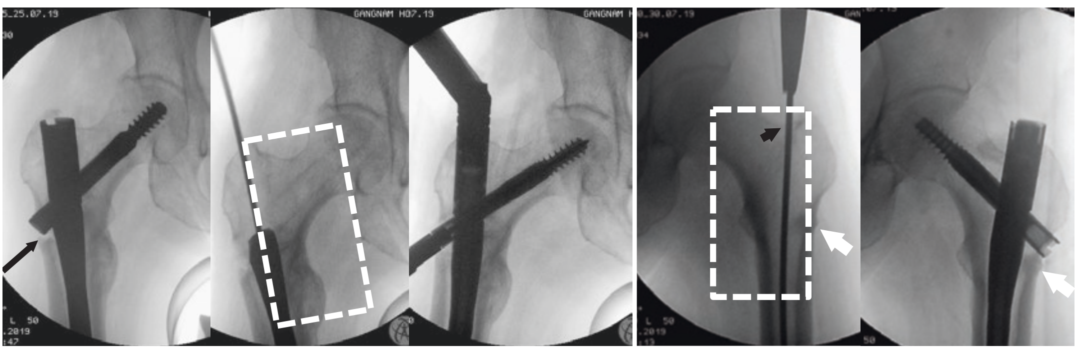


Fig. 8.21 The harmful effect of varus malreduction in the subtrochanteric AFF. The patient complained of right hip pain for 1 year after cephalomedullary nailing that was performed for the treatment of subtrochanteric AFF. The nail was inserted from the apex of the greater trochanter. Callus formation is visible on the medial aspect of the femur, but the radiolucent line underneath the lag screw persists (thin long black arrow). We planned an exchange nailing and bone graft for the lateral cortical defect. However, we realized that the nail was broken at the lag screw hole during the operation. The white rectangle shows the varus malalignment of the proximal femur compared to the rectangle on the left side. The distal part of the nail was removed using a blocking wire technique (See Chap. 9, Figs. 9.9 and 9.10). Nonunion healed uneventfully after exchange nailing and autoiliac bone graft. Prophylactic nailing was performed on the left side because of the endosteal and periosteal callus at the high subtrochanteric area (white arrows). The entry point was made at the medial slope of the greater trochanter (short black arrow). The apex of the greater trochanter was located lateral to the longitudinal axis of the femur in this patient, so inserting the cephalomedullary nail from the tip of the greater trochanter carried the risk of resulting in varus deformity (See Chap. 4, Figs. 4.4, 4.5, 4.6, 4.7 and 4.8). To avoid such an error, I recommend starting from the medial slope of the greater trochanter at all times, regardless of the level of the fracture

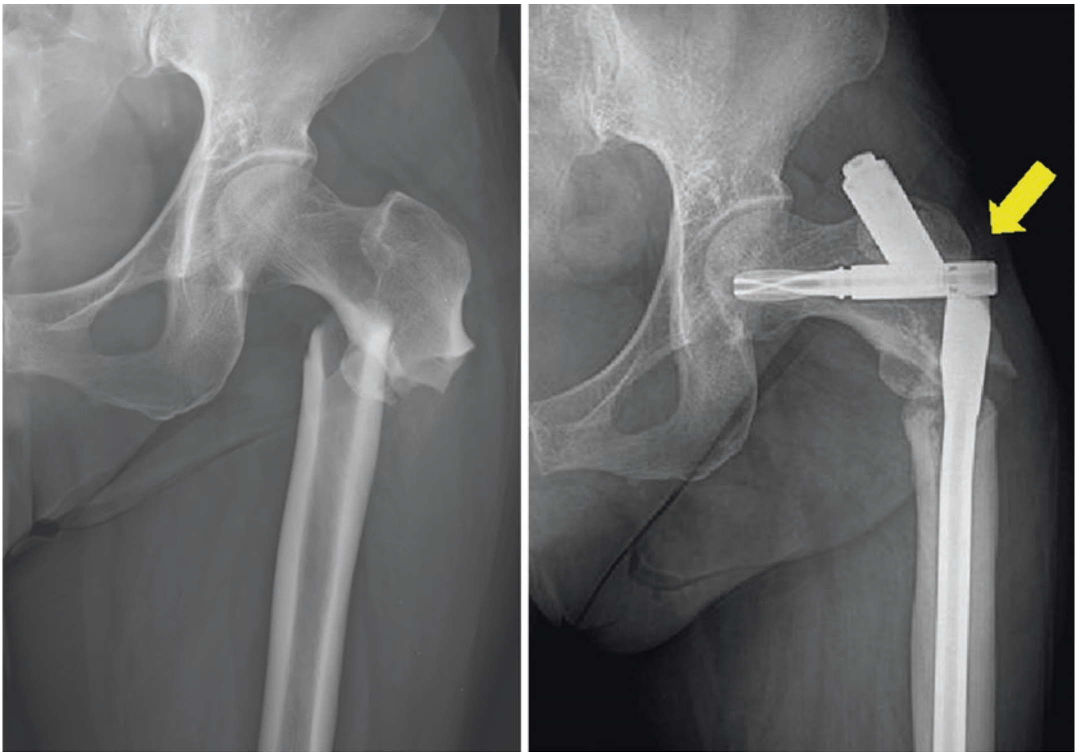


Fig. 8.22 Metal failure and nonunion of high subtrochanteric AFF 7 months postoperatively. Handling the short proximal fragment is complicated. Because of incomplete reduction and the fracture gap in closed nailing, I recommend a dynamic interlocking mode of fixation in the distal part of the nail with augmentation with Poller screws beside the nail if necessary. Persistent gap usually results in nonunion and metal failure in this area (see Chap. 9 for nonunion of subtrochanteric fracture)

IM Nailing for Complete AFF

AFF developed in the femoral shaft is usually associated with varying degrees of femoral bowing. Some surgeons advocated that the greater the bowing, the lower the fracture level. However, we concluded that the bowing degrees are not related to fracture level but the estimated fracture level (Fig. 8.4). In addition, insertion of the straight nail into the bowed femur induces several problems, such as iatrogenic fracture, straightening of the femur, medial gap opening, leg-length discrepancy, the eccentric position of the distal nail tip, delayed union, and nonunion (Fig. 8.23) [22, 23, 28]. In case of excessive anterolateral femoral bowing, several tips are necessary to avoid bursting of the femur during IM nailing. External rotation of the greater trochanter starting antegrade femoral nail converts the anterior bowing of the nail to lateral bowing so that the nail matches with the anterolateral femoral bowing (Figs. 8.16, 8.24 and 8.25).

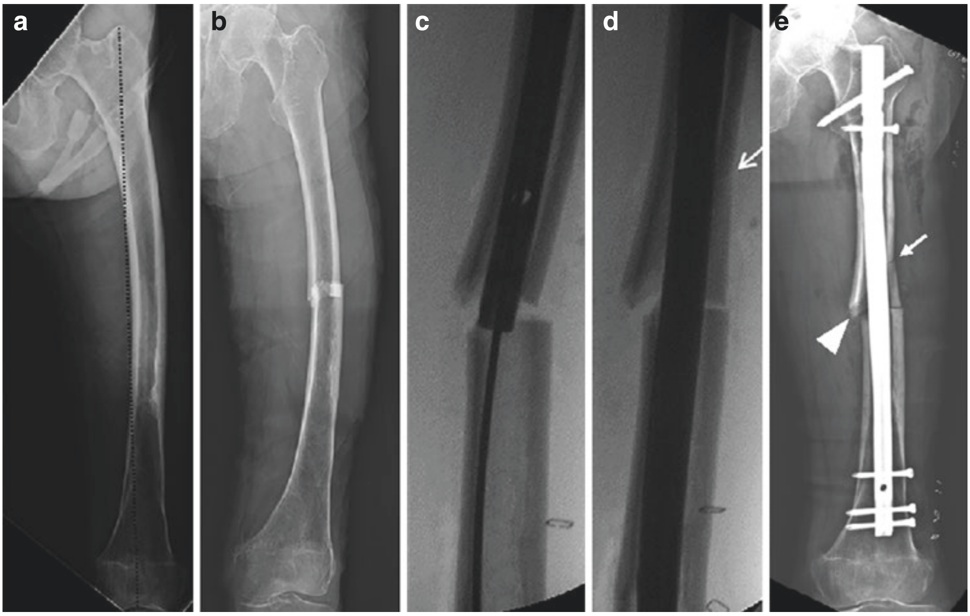


Fig. 8.23 Complications after conventional nailing. Figures (**a**) and (**b**) show complete atypical femoral fracture with grade-III anterolateral bowing. Figures (**c**) and (**d**) show an iatrogenic fracture in the lateral cortex (arrow) when the nail tip passes the apex in the conventional technique. Figure (**e**), postoperative radiograph, shows straightening of the femur, medial gap opening (arrowhead), and iatrogenic fracture (arrow) [23]

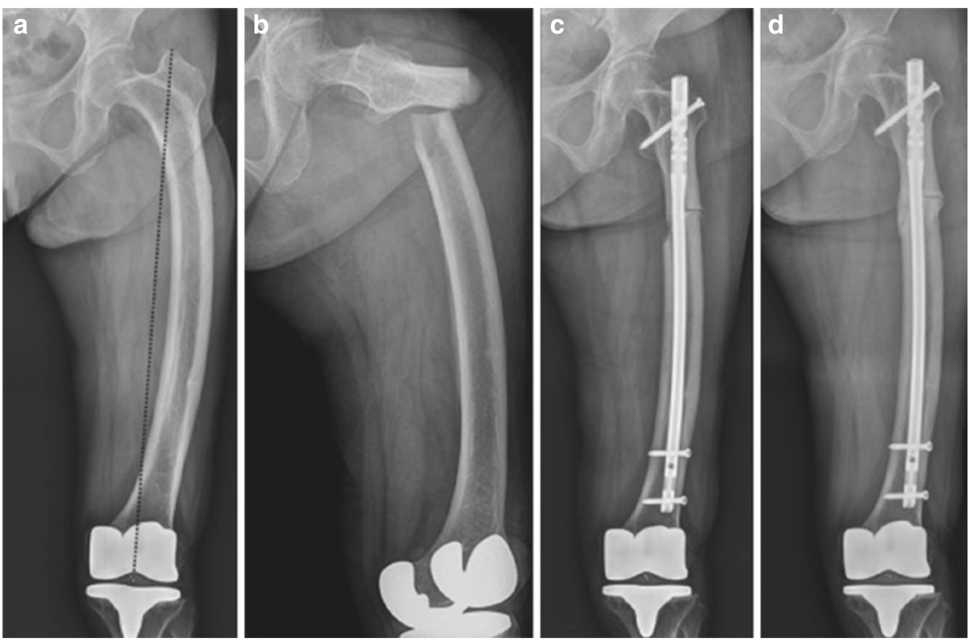


Fig. 8.24 A 77-year-old female patient sustained complete AFF. Figures (**a**) and (**b**) show that this patient had Grade-III anterolateral bowing (a new grading system of femoral bowing in Fig. 8.15) and complete AFF. Figures (**c**) and (**d**); The patient underwent a surgical procedure with the new technique (external rotation of the femoral nail) and demonstrated osseous union at 8 months after the surgical procedure [23]

Fig. 8.25 Use of external rotation nailing technique in AFF with excessive anterolateral bowing. Passage of the straight nail at the apex of the curve opened the fracture site medially (upper right figure), so external rotation of the nail was necessary to decrease the medial gap. The medial gap is not prominent on the postoperative radiography. The drill starting point for distal interlocking was located on the posterolateral aspect of the femur along the supracondylar line (lower right figure: The distal interlocking hole is circular, but the medial and lateral femoral condyles are not overlapped [Two black arrows]). Dynamic mode of interlocking (proximal) closed the gap after weight-bearing and the fracture healed uneventfully

8.9 Other Miscellaneous Causes of AFF or AFF-Like Fractures

1. Zolendronate (Zometa) is a potent bisphosphonate used to treat hypercalcemia and bone metastasis. Higher doses of zolendronate are prescribed for those purposes compared to the treatment of osteoporosis. Repeated use of Zometa also causes AFF (Fig. 8.26). It is usually accompanied by dull thigh pain. Hot uptakes around the hip joint in the bone scan mimic bone metastasis. As is common with the incomplete AFF, a complete fracture may occur after minor trauma. Since Zometa also causes osteonecrosis of the jaw, dental care and examination are crucial in these patients [29].
2. Alendronate has been used to treat Paget's disease. Prolonged use of alendronate causes AFF lesions on the femur as well (but it is not called an AFF by the definition of ASBMR) (Fig. 8.27) [30].
3. Another striking phenomenon is secondary AFF after surgical treatment for primary AFF or other hip lesions. A lag screw hole or various interlocking holes around the subtrochanteric area weaken the tensile strength of the lateral cortex. Accumulation of stress around

Fig. 8.26 A 62-year-old lady was diagnosed with bone metastasis (spine) 5 years after being diagnosed with breast cancer. She took Zometa (zolendronate) medication to delay the spread of bone metastasis. Unfortunately, she sustained a complete subtrochanteric AFF after suffering minor injury while taking a walk. The fracture was reduced and fixed with an antegrade femoral nail in reconstructive mode. Do not miss the white arrow at the lateral cortex of the subtrochanteric area on the left side. Metabolic bone diseases have a high incidence of bilateral lesions. Since she was supposed to keep Zometa therapy, we performed prophylactic nailing for the left incomplete AFF

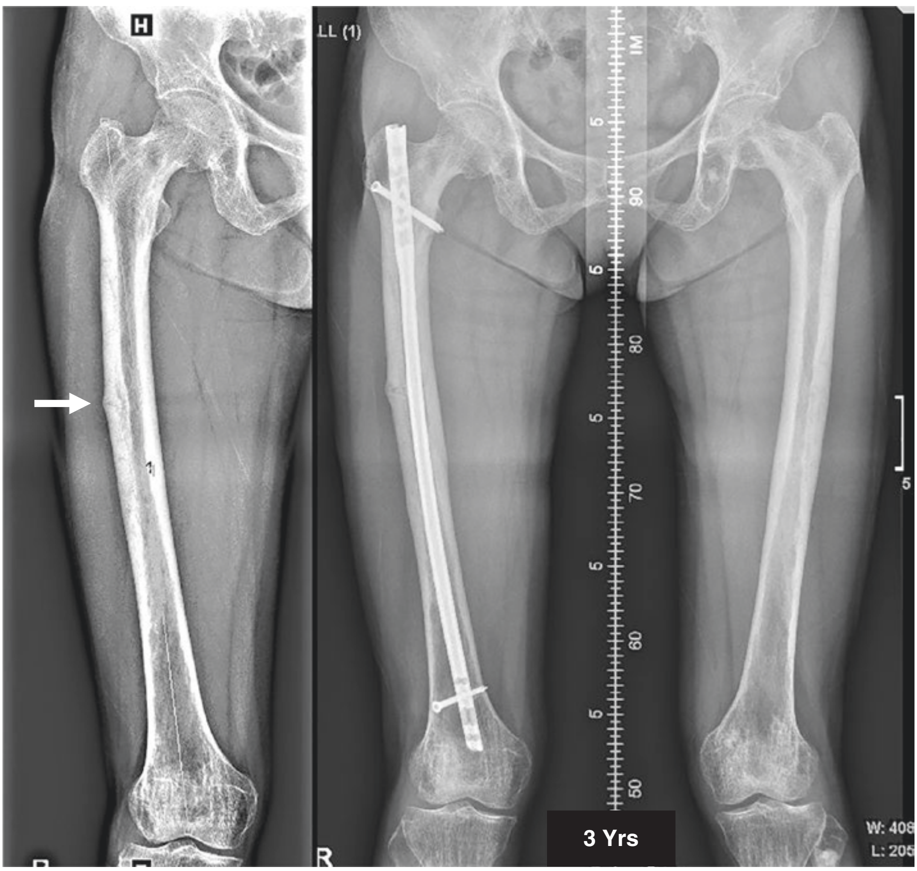


Fig. 8.27 A 66-year-old female patient suffered from Paget's disease on both femora and maxilla. Prophylactic femoral nailing was performed due to progressive bowing, pain, and impending fracture (white arrow). A femoral nail was inserted in external rotation to accommodate excessive anterolateral femoral bowing. Despite the slow healing process of the crack on the femoral bowing apex, the pain subsided 3 years after IM nailing

Fig. 8.28 A 72-year-old lady visited OPD due to dull pain around the left mid-thigh. She was the patient described in Fig. 8.5. Eight years after closed reduction and internal fixation with a short medullary nail, the new lesion developed around the distal interlocking hole (white arrow). Exchange nailing was performed with a long nail. The thigh pain disappeared 6 months after exchange nailing. In AFF, the entire length of the femoral shaft must be covered with a long nail. Otherwise, peri-implant stress fracture may occur at the end of the short implant in the compromised bone due to bisphosphonate intake

the screw hole results in insufficiency fracture, which causes pain and finally a complete fracture (Figs. 8.28 and 8.29). Again, it is not an AFF by the definition of ASBMR [31, 32].

4. Ipsilateral femoral neck fracture after IM nailing for femoral shaft fracture with excessive anterolateral bowing.

   I do not recommend insertion of the contralateral nail (Off-label use) for simple AFF with excessive anterolateral bowing. However, if the ipsilateral femoral neck fracture occurred after IM nailing, the use of the contralateral nail is an attractive option (Fig. 8.30). A detailed explanation of why such modification (off-label use) is essential to solve the patient's problem must be documented and signed by the patient and doctors [20, 33].

5. Protection of middle zone. (Prevention of the fracture between the two implants).

   Many elderly patients sustain hip fracture after total knee replacement and vice versa (distal femoral fracture after total hip replacement). Fixation of the fracture using a long nail is sometimes impossible due to the prosthetic stem. When using a short nail, protection of metal-free middle zone (between the proximal and distal implant) is important to prevent future fracture (Fig. 8.31).

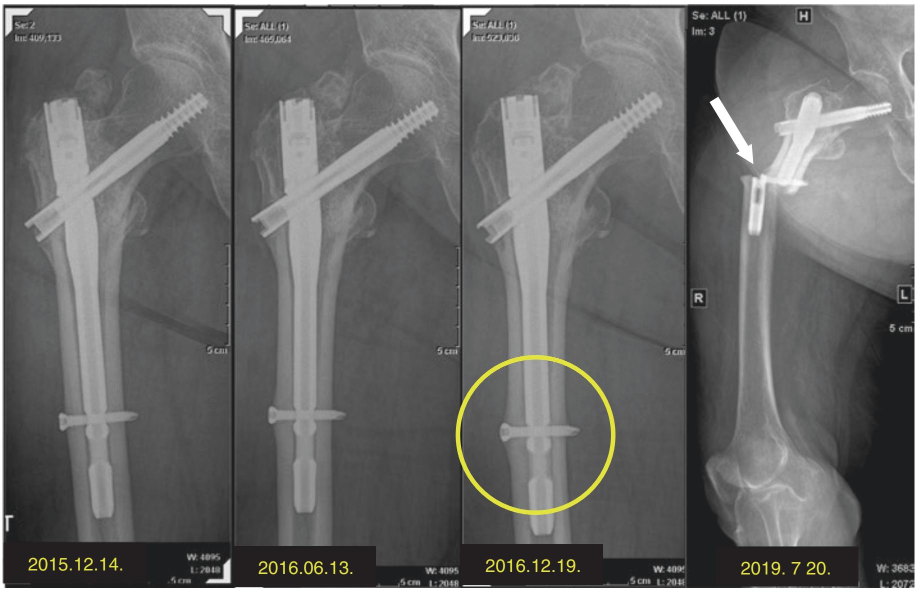


Fig. 8.29 A 70-year-old lady sustained a right intertrochanteric fracture after a simple fall in the bathroom in 2014. The fracture healed uneventfully in 6 months. She took zolendronate 5 mg injection for the prevention of further osteoporotic fracture. At her last visit to OPD, the radiogram showed unusual hypertrophy of the lateral cortex around the distal interlocking hole (yellow circle), but it was overlooked. Then, we lost her follow-up. She returned to the emergency room with a complete fracture and metal failure after a simple fall (5 years after cephalomedullary nailing for trochanteric fracture) (white arrow). The broken nail was removed and replaced with a long cephalomedullary nail

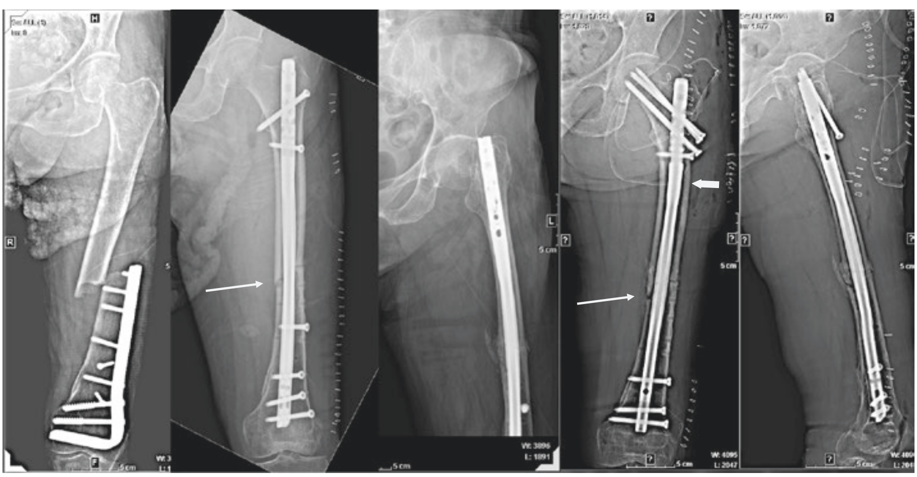


Fig. 8.30 A 78-year-old female patient sustained peri-implant insufficiency fracture after a slip down. Her distal femur was broken 10 years ago and was fixed with a 95° angled blade plate. She recovered uneventfully. We removed the plate and screws and performed IM nailing with an external rotation technique. Slight fracture gap on the medial cortex implicates excessive anterolateral bowing of the femur (long arrows). She fell again and sustained ipsilateral femoral neck fracture 4 months after nailing. Considering the unhealed femoral shaft fracture, we decided to perform closed reduction and internal fixation with a reconstruction nail. However, we could not use the preexisting nail due to external rotation. Due to the bowing of the femoral shaft, we decided to use the contralateral antegrade greater trochanter starting femoral nail to accommodate the femoral bowing (short arrow). We performed exchange nailing using the contralateral nail. Two reconstruction screws and one miss-a-nail screw were inserted into the femoral neck and head after closed reduction. Arthroplasty and lateral plate fixation using a periprosthetic locking plate and wires is another option. The femoral head can be used as an auto-bone graft around the femoral shaft fracture

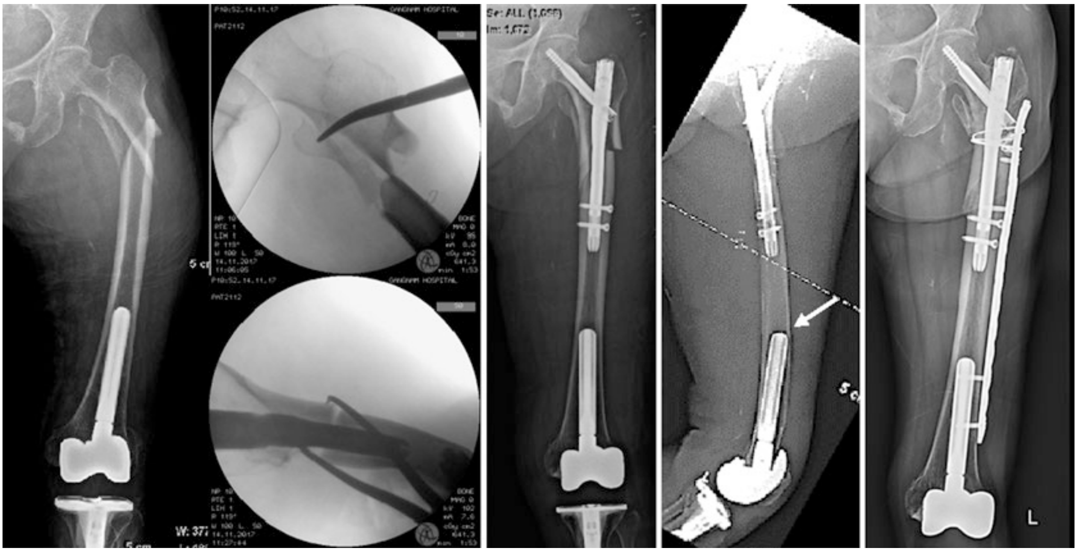


Fig. 8.31 A 78-year-old lady sustained a subtrochanteric AFF-like fracture after a simple fall. There was an unusually large medial fragment around the lesser trochanter, but the main fracture showed typical features of AFF. The proximal fragment was challenging to manage with the hemostatic forceps, so the fracture was open and reduced with bone holding forceps. Due to the long prosthetic stem, we had to insert a short nail. We could identify that the stem of the femoral implant abutted the anterior cortex, which could increase the risk of peri-implant fracture (arrow). We protected the middle metal-free zone with a periprosthetic locking plate using the MIPO technique

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9 Subtrochanteric Fracture: Malalignment and Nonunion After IM Nailing

IM nailing for subtrochanteric or proximal femoral shaft fracture is difficult due to flexion, abduction, and external deformity of the short proximal fragment. The shorter the proximal fragment, the greater the displacement. Traction alone is usually not good enough for closed reduction of the subtrochanteric fracture.

9.1 Tips for Correction of the External Rotation, Abduction, and Varus Deformity of the Proximal Fragment During IM Nailing

The proximal fragment usually has flexion, abduction, and external rotation deformity because of the iliopsoas and short external rotator muscles. Malalignment is usually associated with gaps resulting in many complications, such as nonunion and metal failure. Correcting the proximal fragment deformity is essential before osteosynthesis to prevent these complications (Figs. 9.1 and 9.2). Once the entry site and reaming are made in the wrong site and direction, it is almost impossible to correct the malalignment with a nail inside (Fig. 9.3). I prefer to use the long curved hemostatic forceps to correct the flexion, abduction, and external rotation deformity at first before preparing the entry site. This has already been described in detail in Chap. 4 [1–4]. Lag of cancellous bone and high mechanical strain during ambulation are additional causes of delayed union, nonunion, and metal failure [5, 6].

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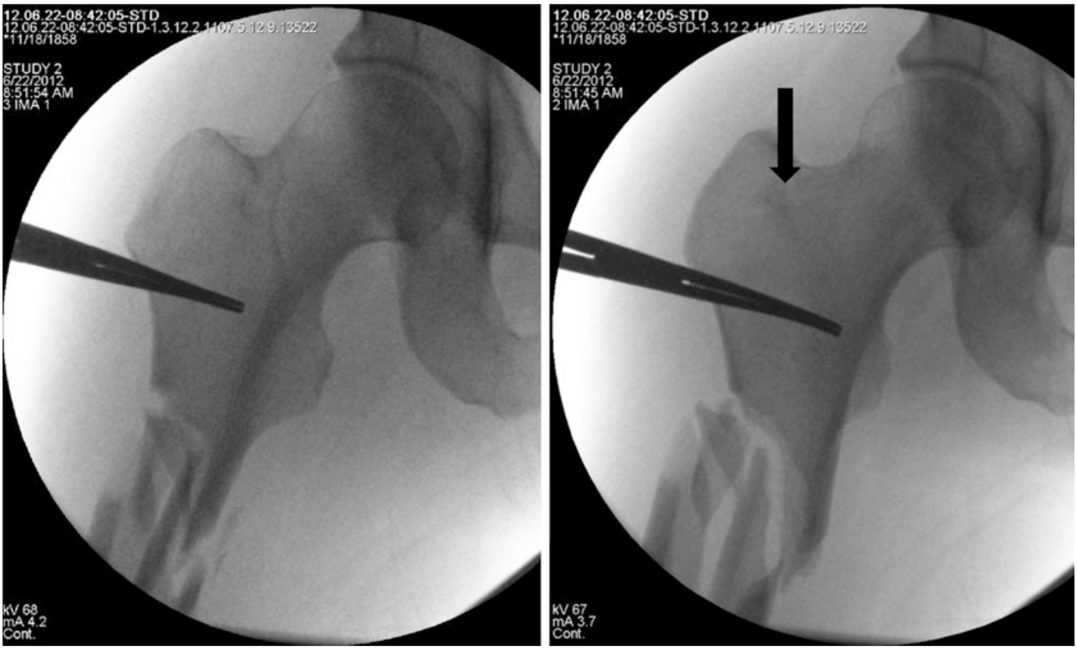

Fig. 9.1 IM nailing for subtrochanteric is difficult due to severe flexion, abduction, and external deformity of the short proximal fragment. The shorter the proximal fragment, the greater the displacement. In general, a stab wound for insertion of the long curved hemostatic forceps is made at the lesser trochanter level. It is usually made at the posterolateral thigh (posterior margin of the femur by palpation). The arms of long curved hemostatic forceps are rolled over the lateral and anterior aspects of the femur. Once they reach the medial edge of the femur (left), internal rotation of the proximal femur is performed by elevating the forceps handles (right). This provides a clear hip AP view and significantly facilitates the preparation of the entry site because the ideal entry site, namely the trochanteric fossa, is well visualized (arrow)

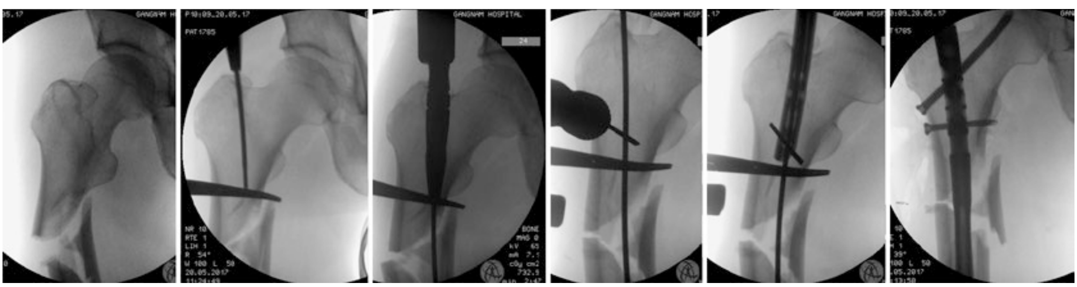

Fig. 9.2 IM nailing for subtrochanteric is sometimes tricky in correcting flexion, abduction, and external deformity of the proximal fragment. Abduction deformity of the proximal fragment was not well controlled during IM nailing even after the introduction of the correcting forceps from the lateral aspect of the femur (three fluoroscopic images on the left). If this deformity were not corrected, the varus would develop when the nail tip advanced into the distal fragment. Varus deformity is detrimental to fracture healing and restoration of the hip function. A Poller pin (Steinmann pin number 2) was inserted into the medial side of the guidewire. Then, the nail was inserted after reaming the medullary canal. The leading edge (slope) of the nail was facing the Poller pin to facilitate insertion of the nail. Abduction deformity was well reduced, and the nail and proximal interlocking screws obtained firm fixation. A Poller pin was removed after proximal interlocking (three images on the right) [3]

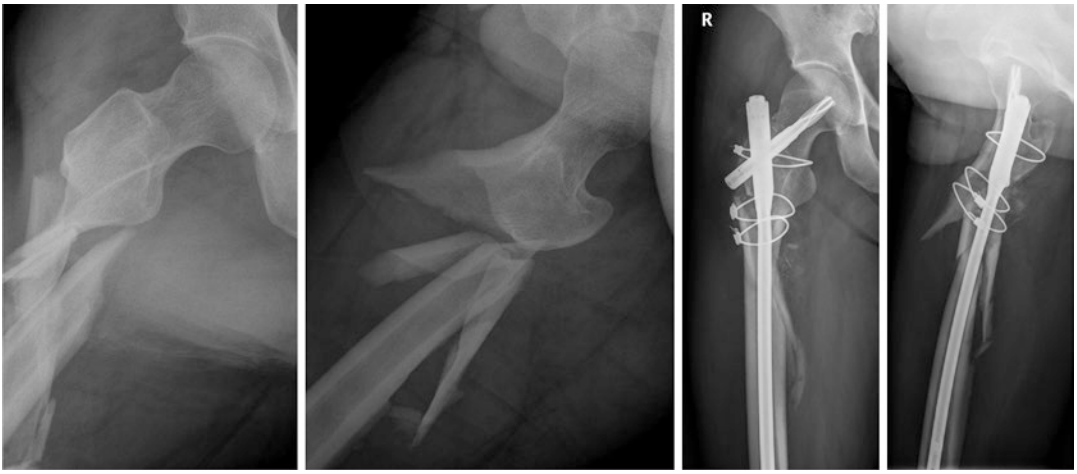

Fig. 9.3 The deformity of the proximal fragment resulted in nonunion of the comminuted subtrochanteric fracture with malalignment. If we made the entry site and reaming in the wrong site and direction, respectively, it would be impossible to correct the malalignment after nailing whatever the methods we would take. The biggest mistake, in this case, was a failure in the correction of flexion and external rotation of the proximal fragment. The size of the lesser trochanter is prominent in the postoperative hip AP view [1]. The flexion deformity is prominent in the lateral view. Of course, the short proximal fragment and comminution at the subtrochanteric area implicated a very tough case for IM nailing. I suggest that wiring the two main fragments prior to IM nailing might be a better option, if the closed methods such as bone hook, Schanz screws, and long curved hemostatic forceps technique have not been successful in reduction. Wiring after IM nailing is usually far less effective in obtaining an acceptable reduction

9.2 Exchange Nailing for Malaligned Subtrochanteric Fracture After IM Nailing

Malalignment in the comminuted subtrochanteric fracture is usually caused by insufficient initial proximal fragment deformity reduction during IM nailing. Exchange nailing for a malaligned subtrochanteric fracture is difficult to perform (Figs. 9.4, 9.5, and 9.6), so osteosynthesis with a fixed angle plate is another good option (Figs. 9.7 and 9.8). We used to open the fracture site for debridement of the massive fibrous tissue and usually need autoiliac bone graft. Treatment of the nonunion of the subtrochanteric fracture after IM nailing is difficult due to malalignment of the proximal fragment and associated wrong trochanteric bony tunnel. After removing the preexisting nail, open reduction of the fracture site and debridement of interposing fibrous tissue are usually necessary to make the correct entry point and new trochanteric bony tunnel for a new nail [7–10]. Sometimes, the removal of broken nails can be challenging [11–14]. Over-reaming and 1–2 mm larger nail insertion are necessary to perform stable fixation after exchange nailing. Long-standing nonunion after cephalomedullary nailing for reverse obliquity intertrochanteric fracture is usually associated with metal failure. Simple exchange nailing is not good enough to dynamize the distal fragment. It is necessary to remove a small block of bone underneath the lag screw. Then the distal fragment migrates proximally to contact the medial column near the lesser trochanter (Fig. 9.6) [15].

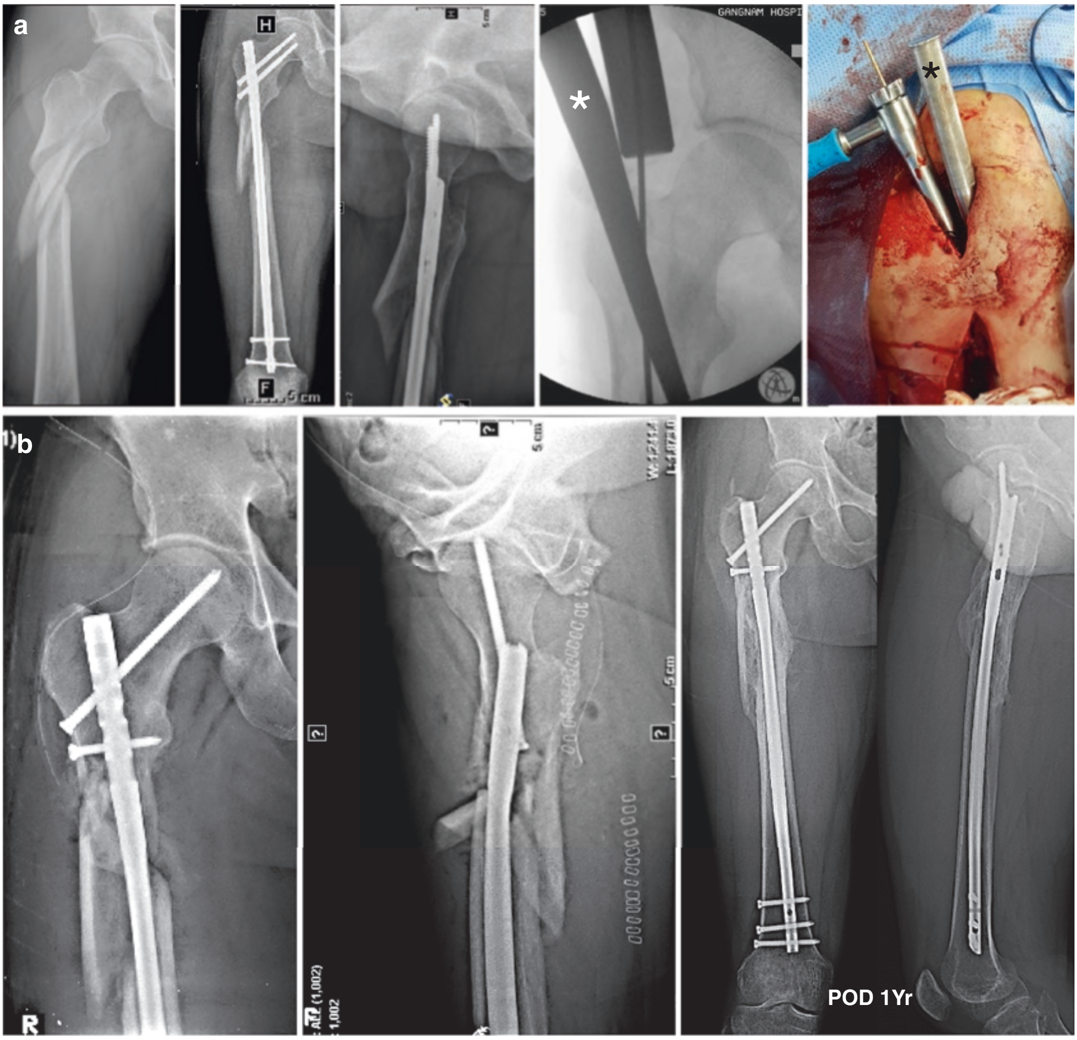

Fig. 9.4 (**a**) A 45-year-old male patient sustained the comminuted subtrochanteric fracture. The initial IM nailing was performed under incomplete reduction of the proximal fragment at a local hospital. Insufficient reduction of flexion and external rotation of the proximal fragment made the butterfly fragment displaced and unreduced. Due to the large gap located medial to the nail in the subtrochanteric area, we decided to revise the nail 1 month after the accident. The nail was inserted from the tip of the greater trochanter. After the removal of the nail, we made a new entry site at the trochanteric fossa. To prevent slippage of the reamer into the preexisting tunnel, we inserted a bone impactor (*) into the tunnel and reamed a new one from the trochanteric fossa (intraoperative fluoroscopic hip AP view and a clinical photography from the lateral aspect of the right hip). (**b**) Exchange nailing was performed after open reduction. We made a new entry point at the trochanteric fossa and the trochanteric tunnel. Flexion and external rotation deformity were corrected, and an autoiliac bone graft was inserted into the medial gap. After the revision, bone union was obtained in 1 year and the nail was removed in 2 years

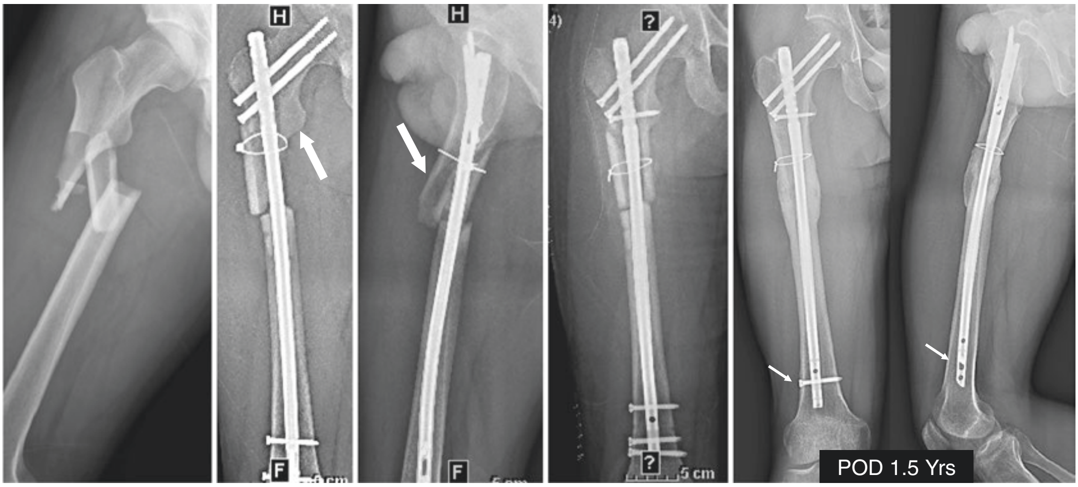

Fig. 9.5 As shown in the previous figures, similar malalignment is noted in the initial postoperative radiographs after IM nailing for the comminuted subtrochanteric fracture performed at a local hospital (arrows). After removal of the nail, we performed an open reduction of the fracture. The cerclage wire was removed and reapplied after the reduction of the displaced butterfly fragment. Next, we inserted a ZNN femoral nail and filled up the defect with the autoiliac bone graft. The nail was dynamized by removing the distal static interlocking screws to promote fracture healing 6 months after revision. The screw in the oblong hole located on the distal part of the nail migrated proximally a few millimeters suggesting successful dynamization, namely closure of the gap at the fracture site (small thin white arrows). Although many surgeons advocate that cerclage wiring has a beneficial effect on reduction of femoral nailing, meta-analysis does not prove that it has statistically significant advantages with respect to risk of reoperation, nonunion, loss of fixation, and implant failure or time to union [1]

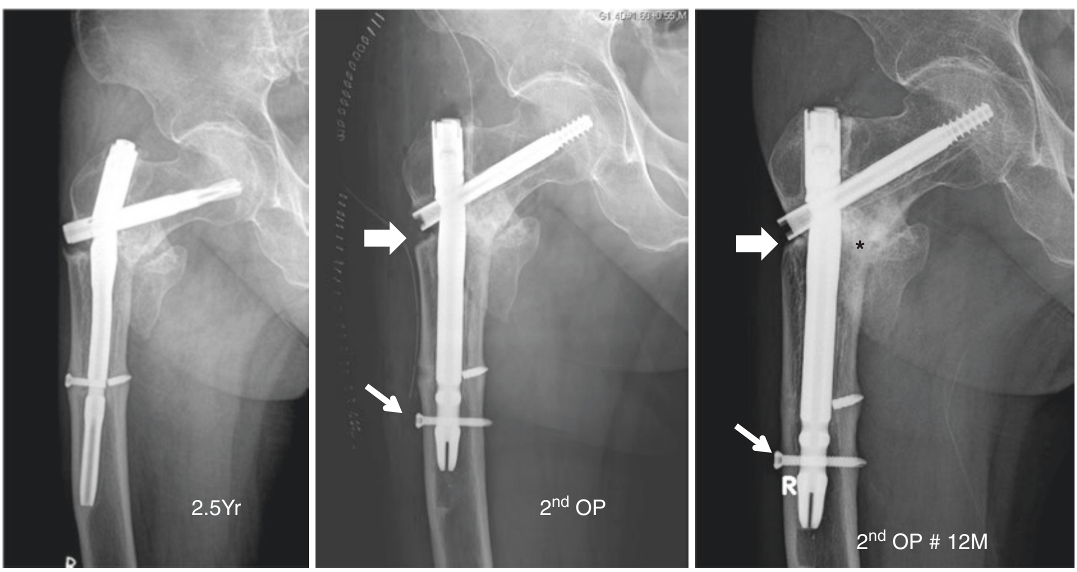

Fig. 9.6 A 65-year-old male patient suffered from a longstanding nonunion after cephalomedullary nailing for reverse obliquity intertrochanteric fracture and metal failure (left). We performed exchange nailing in a dynamic locking mode (thin arrow). To dynamize the distal fragment, it was necessary to remove a small block of bone underneath the lag screw (thick arrow in the middle). Union was obtained 12 months after the surgery. The distal fragment migrated proximally to make contact with the medial column near the lesser trochanter (*) [15]

9.3 Osteosynthesis with a Fixed Angled Plate for Malaligned Subtrochanteric Fracture After IM Nailing

I prefer to use a 95° angled blade plate for this purpose because it provides a stable fixation after fracture site compression by a tension device. This technique is also beneficial in the case of the nonunion after atypical femoral fracture (AFF) (see Chap. 8) (Figs. 9.7 and 9.8) [16].

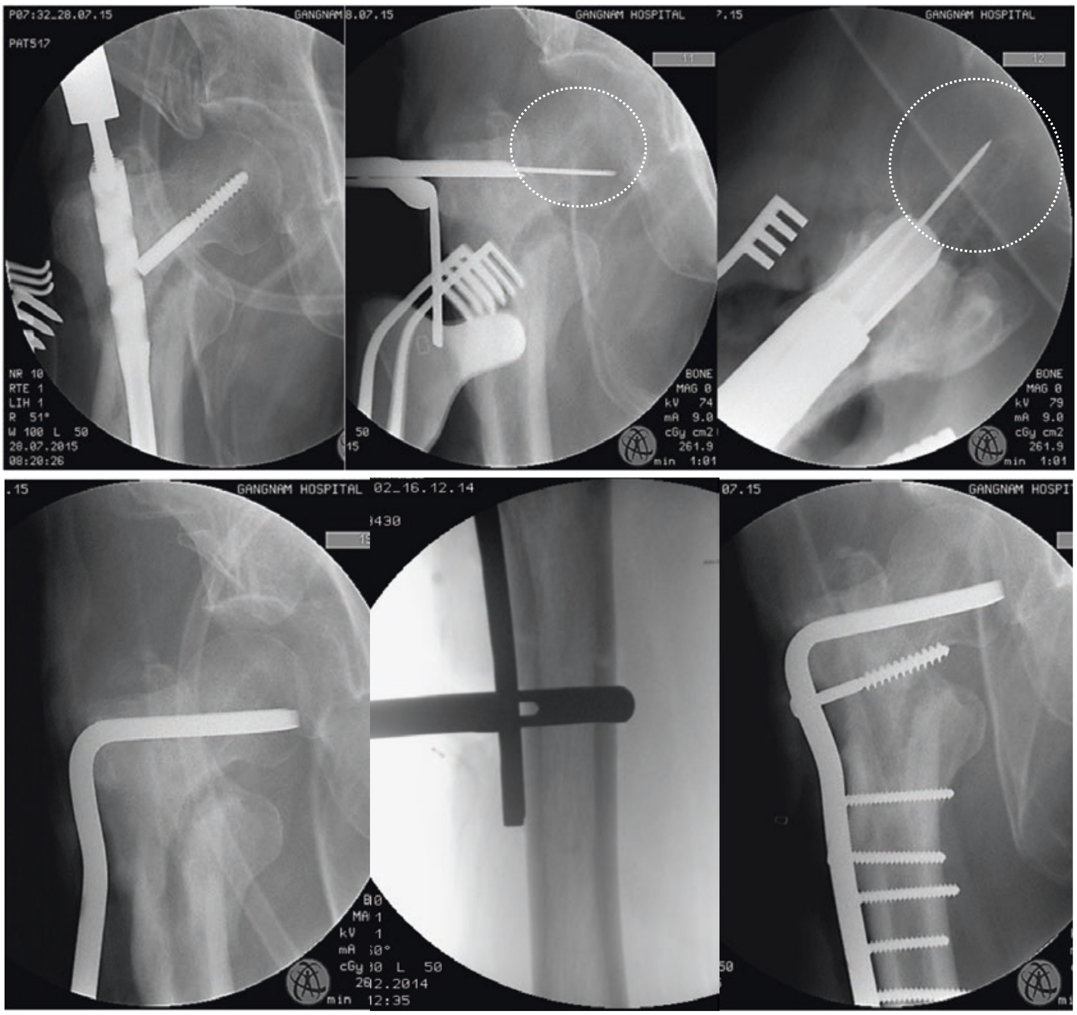

Fig. 9.7 The reverse obliquity intertrochanteric fracture with subtrochanteric extension was treated with reconstruction nailing (single femoral neck and head screw) at a local hospital but failed to get bone union. Due to the medial gap, metal failure, and varus deformity of the short proximal fragment, we decided to remove the nail and broken screw. Then, the plate osteosynthesis using a 95° angled blade plate was performed to correct the varus malalignment and get a firm plate osteosynthesis. The blade was inserted into the lower part of the femoral head in the hip AP view to correct the varus deformity. The blade was advanced into the middle one-third of the femoral neck and head in the lateral view (white circles indicate the femoral head). The gap between the side plate and the lateral aspect of the femoral shaft was compressed using a Lowman bone clamp. This procedure decreased the varus deformity at the nonunion site. A tension device was used to compress the nonunion site, and an autoiliac bone graft was inserted around the fracture site

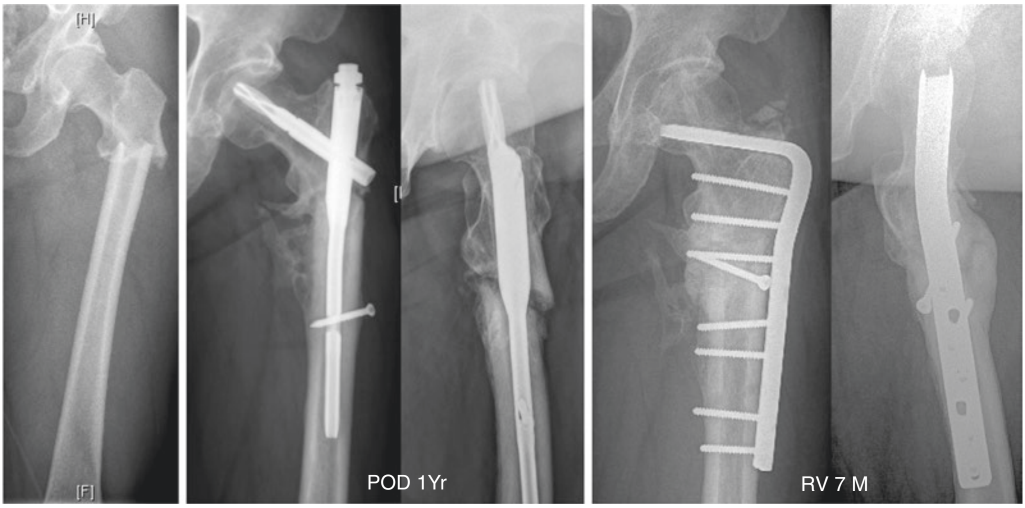

Fig. 9.8 A 53-year-old male sustained a left subtrochanteric fracture. Initially, it was treated with a cephalomedullary nail at a local hospital. Lateral starting of the nail resulted in varus malalignment and subsequent nonunion 1 year after the operation. To correct the varus malalignment, a 95° angled blade plate was inserted using the method described in the previous figure. The level of the greater trochanteric tip was the same as the center of the femoral head. Debridement of the nonunion site and excessive callus was necessary. The autoiliac bone was added around the nonunion site and the fracture united 7 months after plate osteosynthesis. Without varus malalignment, this case would have been treated with so-called lateral notching, which was needed to make distal conventional dynamization effective and to allow for bone healing (see Fig. 9.6) [16]

9.4 Removal of a Broken Nail in Nonunion of the Subtrochanteric Fracture

Metal failure is frequently associated with femoral nonunion. The ball-tip and straight guidewire combination method is the best choice for the removal of the distal part of the broken nail (Fig. 9.9) [7, 12]. A custom-made hook is another useful option if it is available. If such instruments are not available, we recommend a blocking-wire technique to remove a broken hollow intramedullary nail (Figs. 9.10 and 9.11) [12, 14].

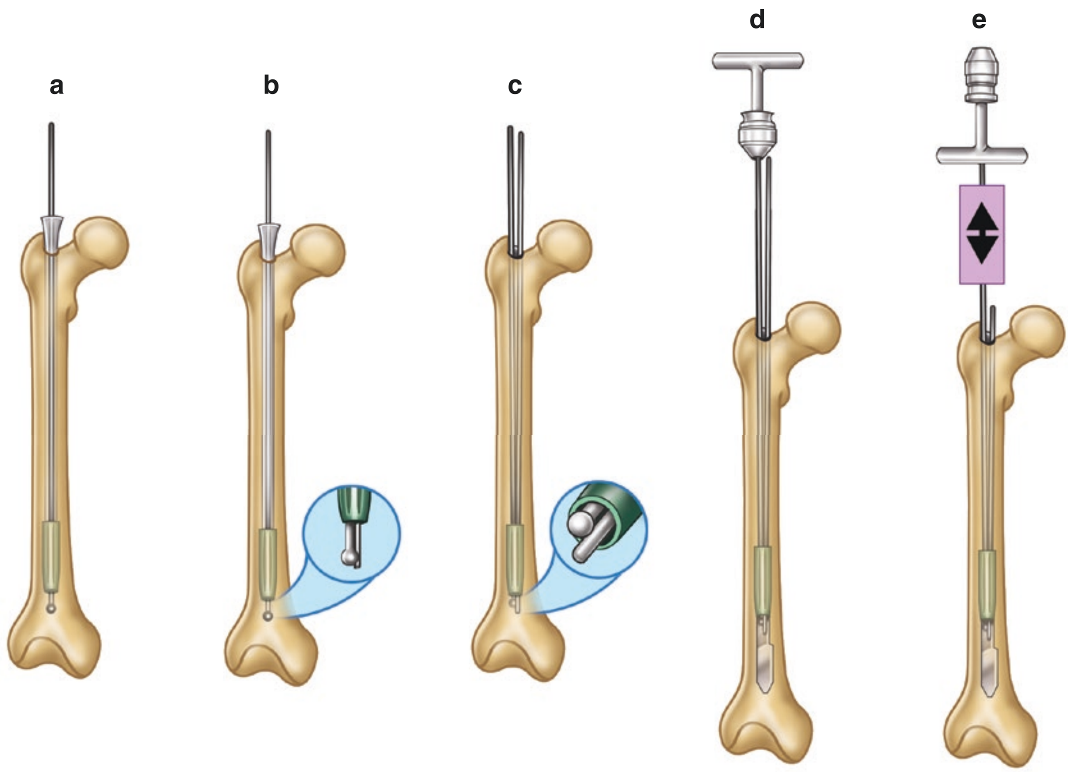

Fig. 9.9 The ball-tip and straight guidewire combination method. After removal of the proximal segment of the broken nail, the medullary canal is reamed to facilitate the removal of the broken distal segment and to allow for exchange femoral nailing. (**a**) The first step is the introduction of a small ball-tip guidewire into the distal femoral fragment through the hollow of the broken nail. (**b**) Then, select the appropriate small diameter straight (smooth) guidewire and repeat process A. (**c**) While holding the straight guide in place, pull the ball-tip guidewire by hand to make the ball-tip and straight guidewires jammed at the distal opening of the broken nail [7]. (**d**) Pull the ball-tip guidewire using a wire holding chuck. (**e**) If it is difficult to remove the distal fragment by pulling it out by hand, insert the slotted hammer into the ball-tip guidewire and hold it with a Steinmann pin chuck or Universal chuck in a reverse manner (to protect the chuck). Hit the chuck handle with a slotted hammer to remove the tightly fitted distal segment of the broken nail (my preferred method). Sometimes, bone ingrowth into the distal interlocking hole makes removal of the distal segment very difficult

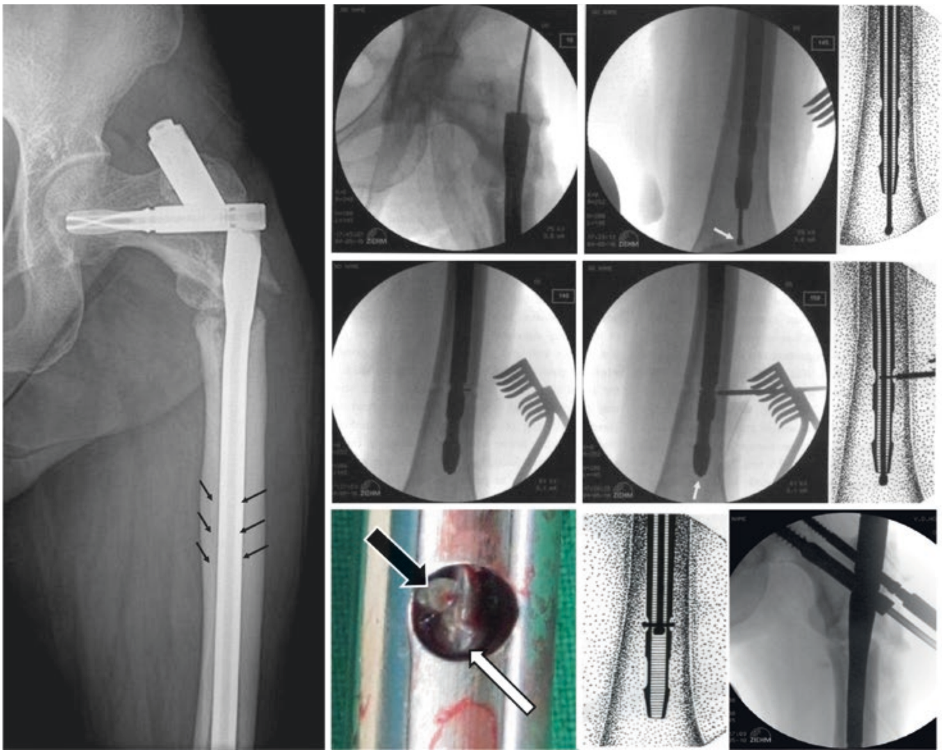

Fig. 9.10 Nonunion of the subtrochanteric fracture was associated with a broken nail at the lag screw hole. The nail was tightly fixed in the shaft (multiple small black arrows). Because of the narrow hollow of the nail, the hook was not eligible. We decided to introduce a ball-tip guidewire into the distal segment of the broken nail. The white arrows indicate the position of the ball tip (right upper column). Then, we introduced a small piece of Kirschner wire (12 mm in length and 1.6 mm in diameter) into the distal static interlocking hole of the broken nail after removing the interlocking screw. A blunt Steinmann pin was used to push the Kirschner wire into the interlocking hole (right middle column). Holding a small piece of Kirschner wire is so tricky that these days we carry it inside a large gauge long needle and push it into the interlocking hole with a stylet. Fluoroscopic control is mandatory. Clinical photography and illustration demonstrate how the blocking Kirschner wire (big black arrow) jams with the ball-tip guidewire (big white arrow) at the static interlocking hole. Exchange nailing was performed after removal of the broken nail (right lower figure). If the 1.6 mm Kirschner wire fails to block the ball-tip guidewire, we can use a number one or two Steinmann pin instead for a larger diameter femoral nail [14]

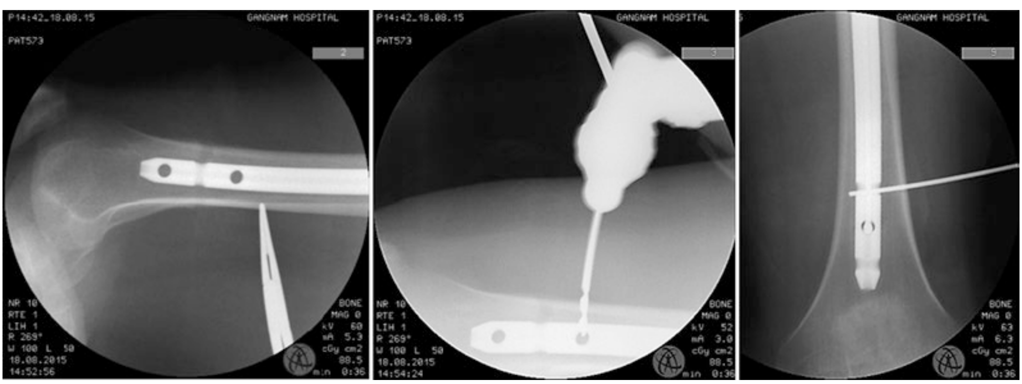

Fig. 9.11 If there is no distal interlocking screw to remove in the distal fragment, make an interlocking hole by the freehand technique. Once the drill hole is made correctly at the nail's interlocking hole, we can pass a blocking K-wire through it. The right image shows the test whether the K-wire is thick enough to jam the ball-tip guide wire

9.5 Nonunion of the Subtrochanteric Fracture After IM Nailing with the Appropriate Alignment

The gap in the subtrochanteric fracture after osteosynthesis has been known as the cause of various complications such as nonunion and metal failure. Compared to the nonunion of the subtrochanteric fracture with a malalignment, treating nonunion with the appropriate alignment is easier because we can skip the reduction process. There are two methods to overcome the gap problem: the first is the exchange nailing technique with a larger diameter nail in a dynamic interlocking mode (Fig. 9.12) [17–19]; the second is the plate augmentation technique with bone graft (Figs. 9.13 and 9.14) [18, 19]. I prefer the exchange nailing technique, but the benefits of dynamic mode have not been well defined yet.

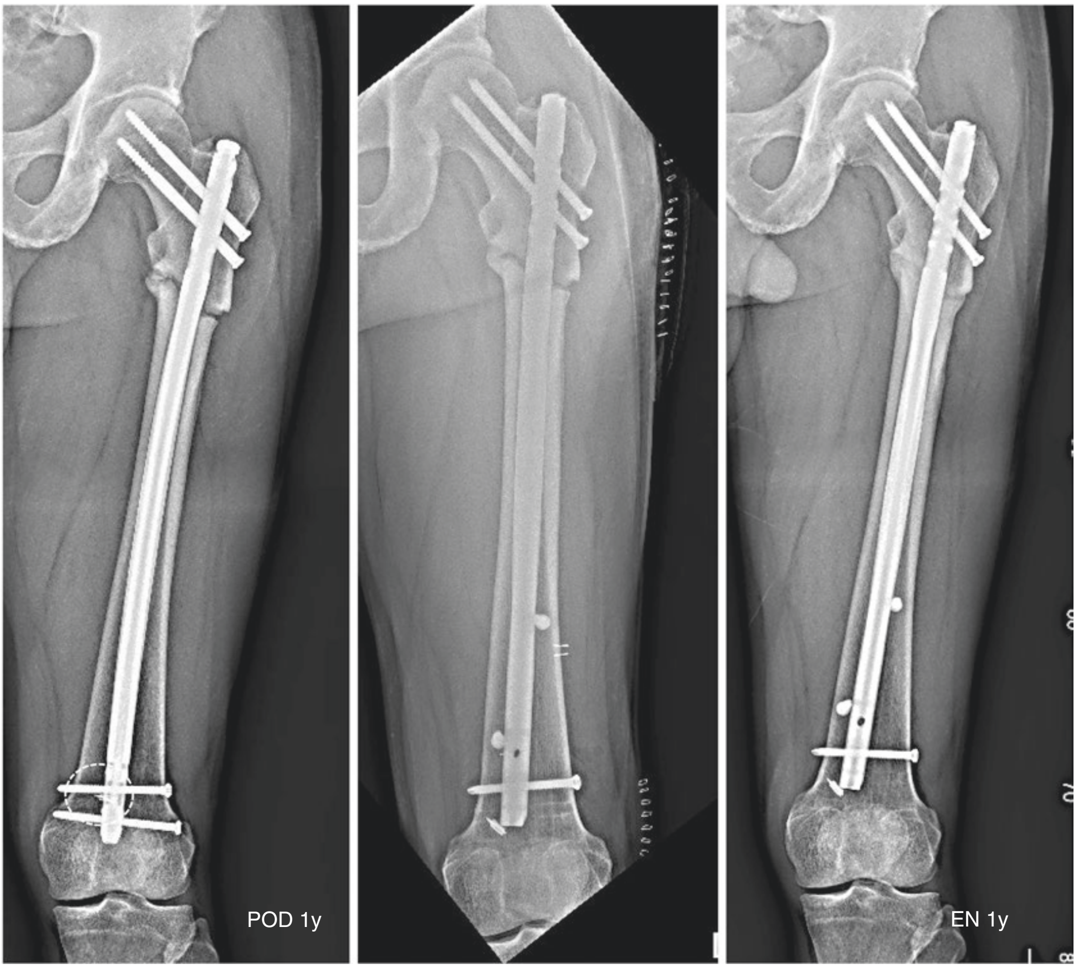

Fig. 9.12 A 53-year-old man sustained a subtrochanteric fracture and was treated with IM nailing at a local hospital. The drill tip was broken and remained in the medullary canal (white circle). The subtrochanteric nonunion developed due to a gap at the fracture site 1 year after the operation. There was slight callus formation on the medial cortex only. Therefore, we decided to perform the exchange nailing in a dynamic interlocking mode. Since only one dynamic oval interlocking hole is available in the dynamic locking mode, we augmented the distal fixation with two Poller screws on both sides of the nail. The fracture was united with proximal migration (dynamization) of the distal fragment 1 year after exchange nailing

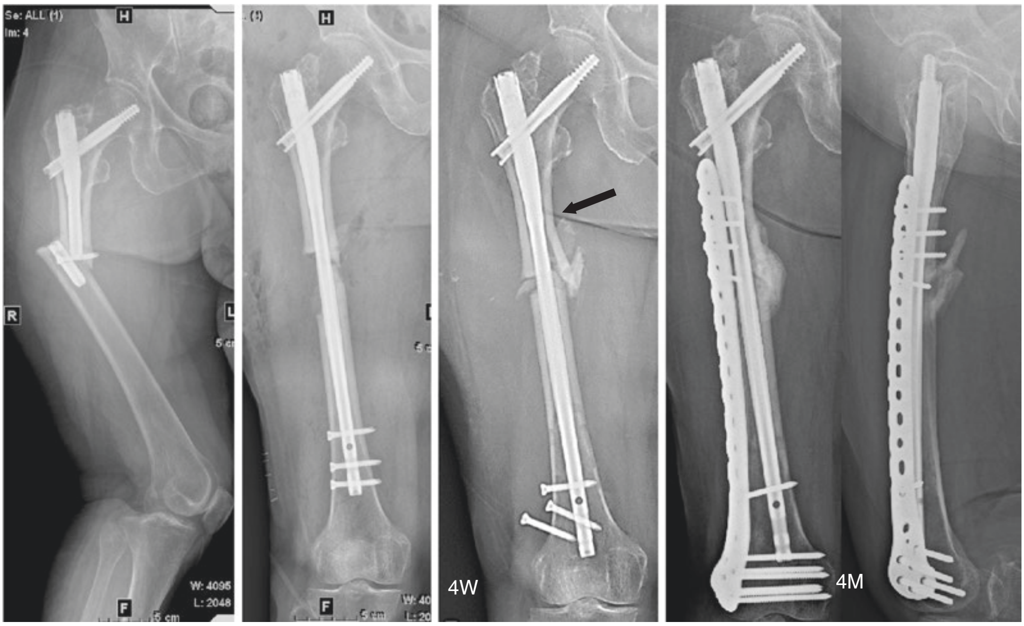

Fig. 9.13 An 81-year-old female patient sustained a secondary AFF-like fracture through a proximal interlocking screw hole at the subtrochanteric area (See Chap. 8, Fig. 8.28) [20, 21]. Due to difficulties during the removal of the broken nail, the lateral bony window was made at the lateral aspect of the proximal femoral shaft. The defect on the lateral cortex was evident in the postoperative radiography. The system collapsed 4 weeks after the operation. All three distal interlocking screws failed to hold the cortex, and the medial cortex was broken (black arrow) with shortening of the femur. The fracture healed 4 months after plate augmentation and autoiliac bone graft

Fig. 9.14 A 66-year-old man underwent cephalomedullary nailing for the subtrochanteric fracture at a local hospital 1 year ago. He visited our OPD due to nonunion of the left subtrochanteric fracture. CT examination revealed a gap at the fracture site and slight varus malalignment. We performed the plate augmentation for the fracture site and reinsertion of the distal interlocking screws using the unused holes for distal enforcement. The fracture site was stabilized and healed in 4 months after the plate augmentation (PA)

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10 Isthmic or Non-isthmic Femoral Nonunion After IM Nailing

Most surgeons agree that IM nailing is the treatment of choice for femoral shaft fracture. The union rates of femoral nailing range from 97% to 99.1%. The introduction of interlocked nailing has decreased the risk of shortening after nailing, but some limited cases have still been complicated with nonunion after IM nailing [1–5]. The main mechanical problem that causes nonunion in the interlocked IM nailing system is rotational instability (Fig. 10.1). Exchange nailing is an excellent choice for aseptic nonunions of non-comminuted diaphyseal femoral fractures, with union rates reported to range from 72% to 100% [6–10]. The location of nonunion is an important factor in exchange femoral nailing (Fig. 10.2)

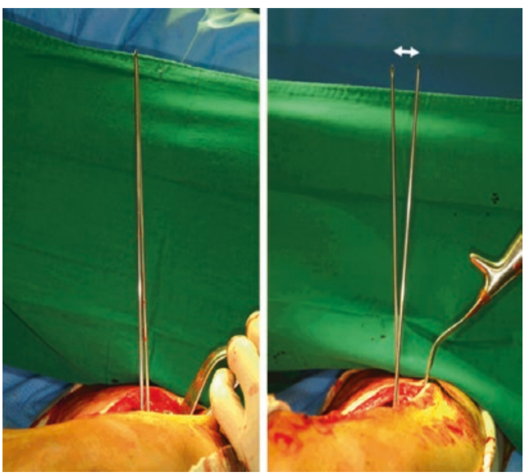

Fig. 10.1 Intraoperative finding depicting rotational instability in the nonunion of the femoral shaft after IM nailing. A Steinmann pin was inserted in the proximal and distal fragment perpendicularly to the long axis of the femur, respectively (left). Then, the limb was twisted to see if there was a rotational instability. The instability can be measured by the angle between the two Steinmann pins (right)

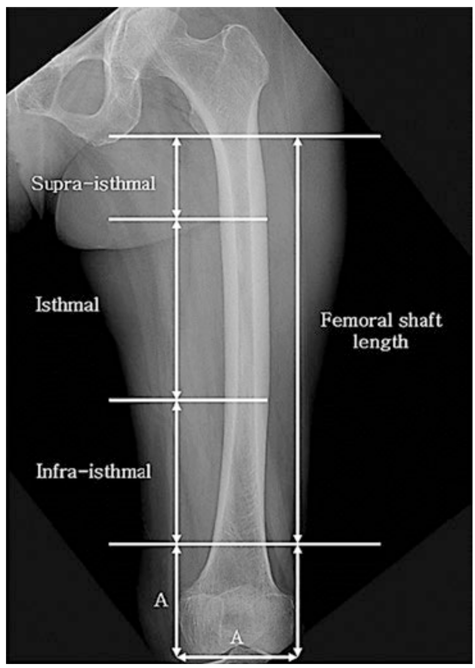

Fig. 10.2 Definition of the length of the femoral shaft and its anatomic division into three levels (supra-isthmal, isthmal, and infra-isthmal) according to the metaphyseal flare and isthmus. The lengths of the three levels (supra-isthmal, infra-isthmal, and isthmal) are different. The length of infra-isthmal is always longer than that of supra-isthmal. (A indicates transepicondylar width)

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[11–13]. History of comminuted and open fracture are other risk factors of exchange nailing [14].

10.1 Supra-Isthmal Nonunion

Exchange nailing using a larger nail that is usually 1–2 mm larger in diameter and 2 cm longer is quite effective in nonunion after noncomminuted fracture if the alignment of the main fragments is good (Fig. 10.3). Overreaming is essential to insert a larger diameter nail for better contact and stability. I prefer to use a longer nail to avoid a preexisting distal locking hole in the femur. The dynamic locking mode is recommended in nonunion with a gap. Insertion of an interlocking screw in the oval (oblong) hole, namely dynamic interlocking, is recommended in the proximal part of the nail if the nail is manufactured for us to do so. The reasons are: first, the correct placement of the interlocking screw at the proximal edge of the oval hole (the location far from the fracture or nonunion site) is possible using the targeting guide; Second, the cortex is thicker in the proximal femur than in the distal one. If the proximal fragment is too short to fix with a dynamic proximal interlocking screw alone, augment the distal dynamic interlocking with two Poller screws on both sides of the nail (see Fig. 9.12 in Chap. 9, Subtrochanteric fracture: Malalignment and nonunion after IM nailing). Previous open nailing and wiring with a substantial defect is a good indication of plate augmentation and bone graft (Fig. 10.4) [11, 14–16].

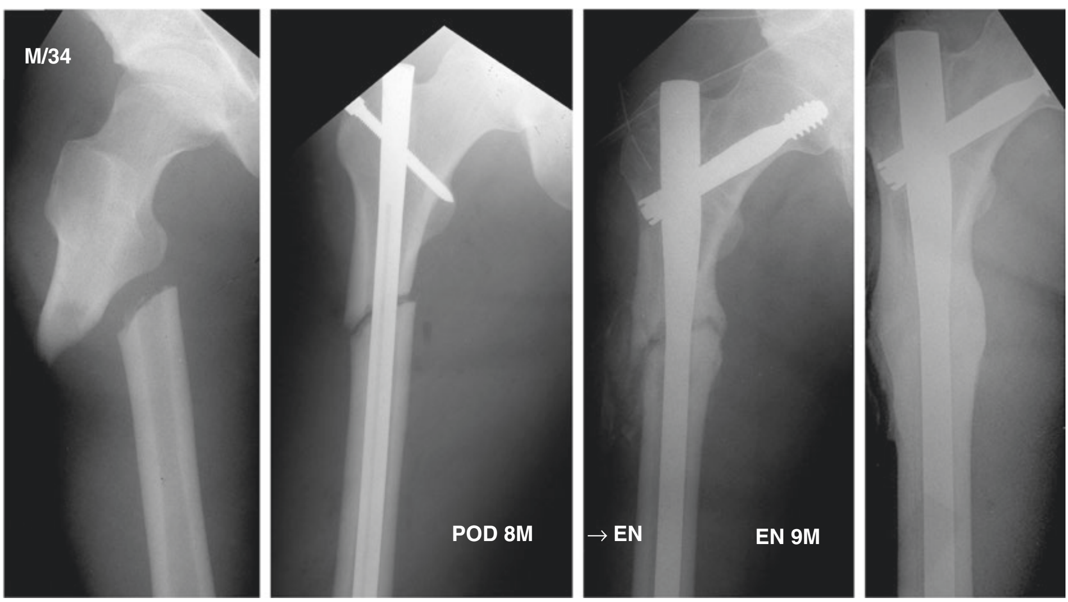

Fig. 10.3 A 34-year-old male sustained an oblique subtrochanteric fracture after motor vehicle accident. We performed closed reduction and internal fixation using a slotted femoral nail (GK femoral nail). A gap is noted at the fracture site and was deleterious to fracture healing in the subtrochanteric area. Consequently, the nonunion developed. We exchanged the femoral nail using a nonslotted cephalomedullary nail (long Gamma nail) for firm fixation of the proximal fragment. The fracture healed 9 months after exchange nailing

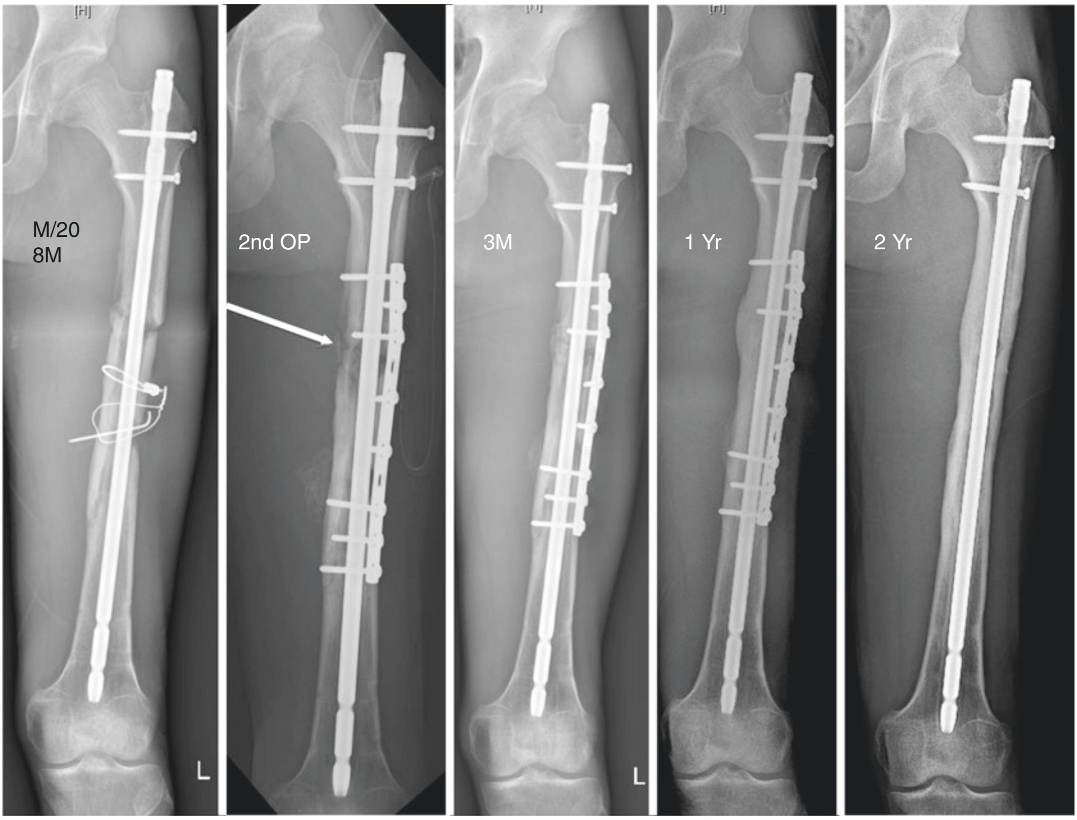

Fig. 10.4 A 20-year-old male sustained a segmental femoral shaft fracture 8 months ago. A surgeon at a local hospital performed open reduction and internal fixation using a nail and wires. Dynamization was performed to enhance fracture healing but was ineffective. Then, he visited our OPD clinic. We decided to augment the fracture fixation with a plate and insert an autoiliac bone at the defect because the comminution and previous open procedure were risk factors of the exchange nailing (white arrow). A solid union was obtained 1 year after plate augmentation. The plate was removed due to irritation 2 years after the operation

10.2 Isthmal Nonunion

Exchange nailing is the treatment of choice for the nonunion in the isthmal zone. I do not think the mode of interlocking critically affects postoperative care; I prefer static interlocking mode if there is a minimal gap at the nonunion site (Fig. 10.5). However, I believe that the dynamic mode of interlocking is preferable in the isthmal nonunion with a gap (Fig. 10.6). Alignment is usually good, so less invasive procedures, such as the removal of a preexisting nail, reaming of the medullary canal, and insertion of the larger nail, are sufficient. Bone defect, previous open fracture or open procedures such as cerclage wiring and the presence of nonviable bone are the risk factors of exchange femoral nailing. I recommend plate augmentation and bone graft rather than exchange nailing to deal with such risk factors (Fig. 10.7).

Fig. 10.5 (**a**) A 15-year-old female patient sustained mid-shaft femoral fracture. She underwent closed IM nailing (greater trochanter starting technique to protect the lateral epiphyseal artery: white arrow). There was no callus formation around the fracture site for 7 months. Removal of the distal interlocking screw (dynamization) seemed to aggravate the rotational instability, which resulted in nonunion. I performed exchange nailing using a larger diameter nail in the dynamic locking mode. The fracture healed in 6 months. I believe that the dynamic locking mode is essential for successful treatment of the nonunion whenever possible in the proximal and middle one-third of the femoral shaft. (**b**) I would like to take the case of a 13-year-old boy to once again focus on the avascular necrosis of the femoral head after IM nailing. The nail entry was medial to the tip of the greater trochanter (white arrow). The avascular necrosis of the femoral head developed at the weight-bearing area (small back arrows). Surgeons should refrain from using the trochanteric fossa entry point to avoid this kind of disaster in juvenile patients

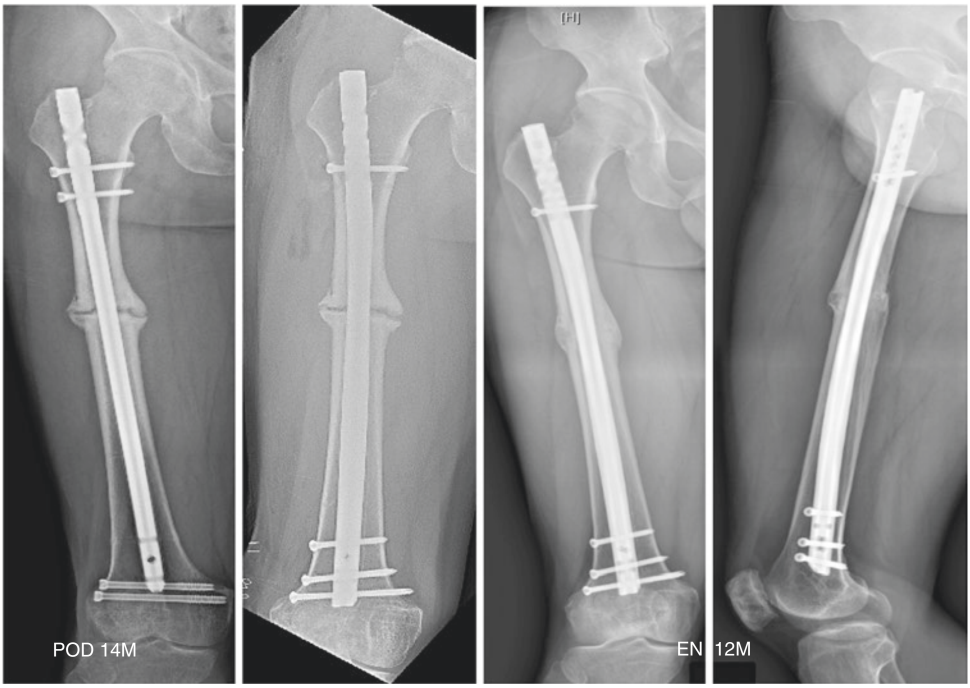

Fig. 10.6 A 40-year-old man sustained a femoral shaft fracture due to a motorcycle accident. He underwent closed femoral nailing in the static mode. Dynamization was performed to enhance fracture healing but was ineffective. He came to our clinic 14 months after the accident. We performed exchange femoral nailing in the dynamic locking mode. The solid union with callus remodeling was obtained 1 year after exchange nailing. Migration of the proximal interlocking screw was not detected

Fig. 10.7 The nonunion developed after open nailing and wiring of the comminuted fragments. Due to the bone defect (arrow) and the possibility of nonviable fragment at the fracture zone, we performed open procedures, such as wire removal, debridement, plate augmentation, and autoiliac bone graft. A solid union was obtained 1.3 years after the operation

10.3 Infra-Isthmal Nonunion

Based on the available literature, exchange nailing alone cannot be recommended for distal femoral nonunions. The increase in the contact area between the nail and bone by medullary reaming is not expected in the infra-isthmal zone. Therefore, some kinds of augmentation are necessary for association with the exchange nailing in the infra-isthmal zone: Poller screw (Fig. 10.8) [17] or plate augmentation (Figs. 10.9, 10.10, and 10.11) [11, 14–16].

Exchange nailing using a larger diameter nail after reaming has been an effective treatment option for femoral shaft nonunion following prior intramedullary nailing. However, substantial uncertainty and controversy remain regarding the effects of interlocking mode on the healing of nonunion. Based on our study of 48 patients with femoral shaft nonunion after IM nailing, the success rate of the index surgery was significantly higher in the dynamic group than in the static group (100% vs. 75%, $p = 0.011$) [17–19]. So, I recommend the dynamic locking mode in the exchange femoral nailing whenever it is possible. Augmentation with two Poller screws enhances the distal fixation (Fig. 10.12) [20–22].

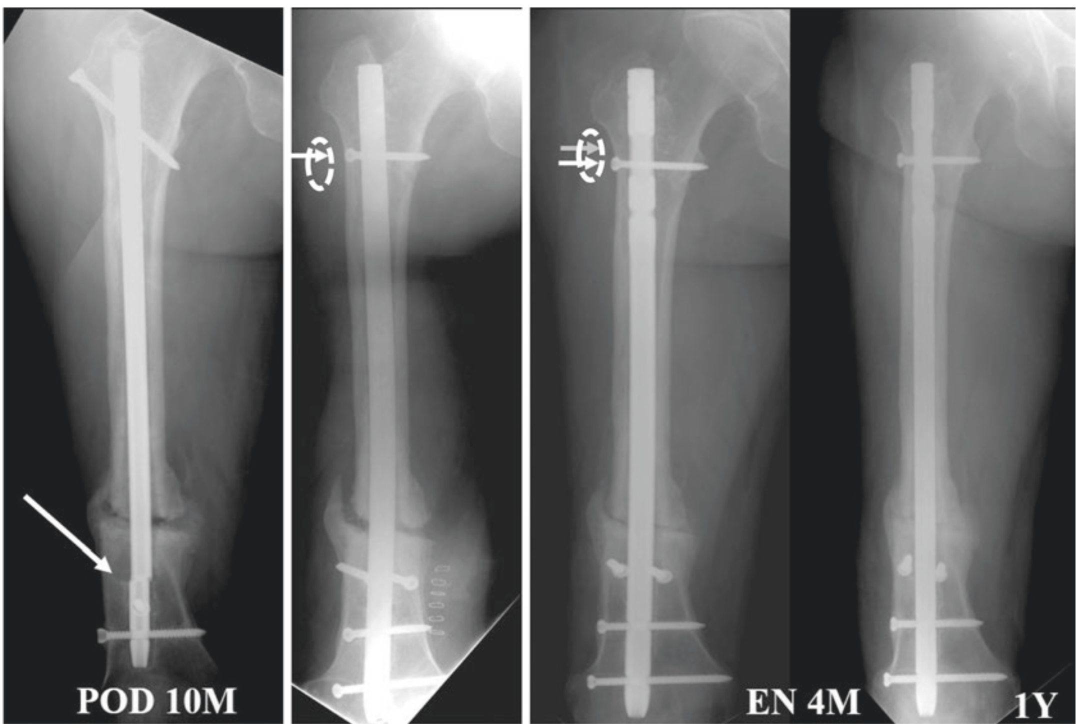

Fig. 10.8 A 63-year-old female patient came to the OPD clinic due to nonunion of the femur at the infra-isthmal area and metal failure. The long arrow indicates the nail breakage. Exchange femoral nailing in the proximal dynamic mode was performed due to the gap at the fracture site. Two Poller screws were inserted on both sides of the nail to augment the distal fixation. The gap closed, and the proximal interlocking screws migrated from the proximal edge of the oval hole to the distal one in the nail. The small white and grey arrows indicate the position of the proximal interlocking screw in the oval hole. The fracture healed 1 year after exchange nailing

Fig. 10.9 Nonunion at the infra-isthmal zone was treated with plate augmentation and bone graft. Due to the scanty callus and the defect at the fracture site, the chance of successful healing was slim at 6 months after nailing. We decided to perform plate augmentation (PA) and bone graft because exchange nailing would not increase the contact area between the nail and femoral cortex. A solid union was obtained 1 year after the operation

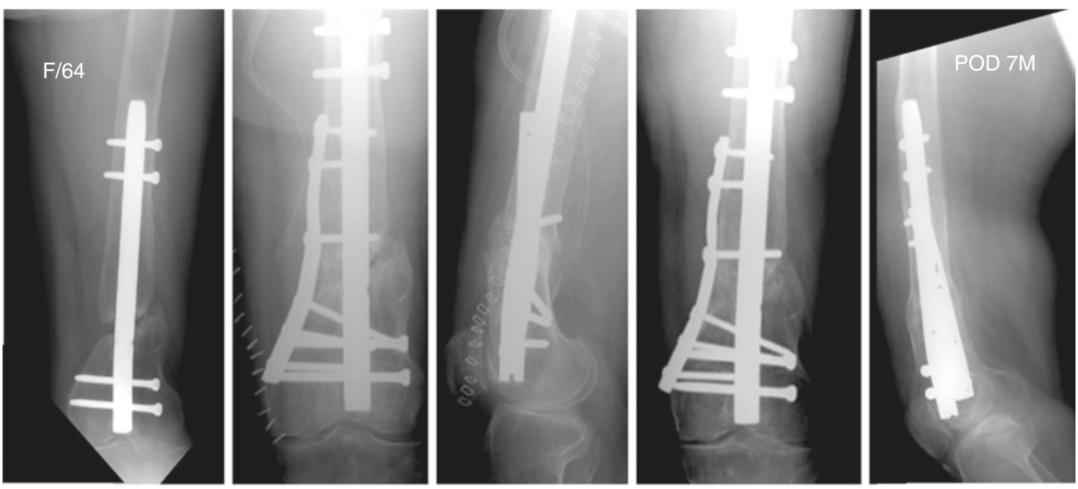

Fig. 10.10 Example of the plate augmentation and bone graft in supracondylar nonunion after retrograde nailing. The nail was undisturbed unless the tip was prominent at the femoral condyle. Exchange nailing is usually not helpful due to large medullary canal in this area. Plate augmentation and bone graft are good options. A bone union was obtained 7 months after the operation

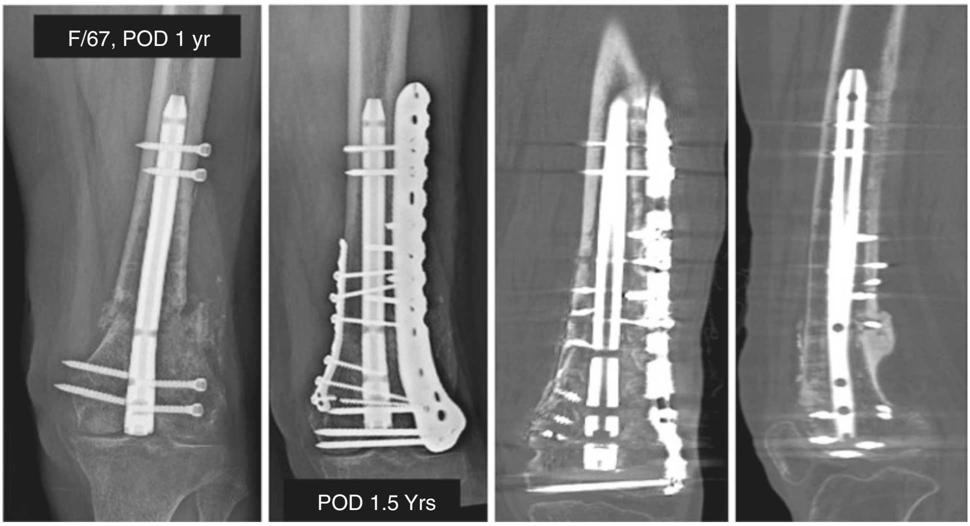

Fig. 10.11 A 67-year-old female sustained distal metaphyseal comminuted fracture of the left femur 2 years ago. She underwent plate osteosynthesis at first but failed to get bone union due to plate breakage. The surgeon performed nail conversion using a retrograde nail. It resulted in metal failure (screw) and nonunion again (left figure). Distal migration of the nail tip irritated the joint surface and an extreme knee joint stiffness precluded nail removal through the knee joint. We removed all interlocking screws and mobilized the nail proximally by traction of the distal fragment about 10 mm. Then, we performed plate osteosynthesis using medial and lateral locking plates. Nonunion healed 1.5 years after plate augmentation and autogenous bone graft

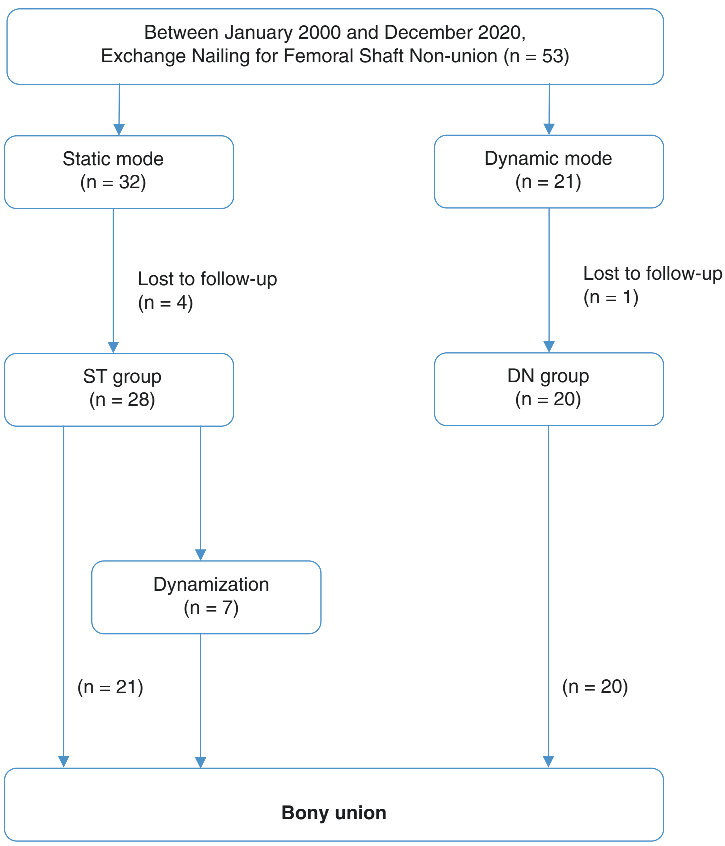

Fig. 10.12 Based on our study of 48 patients with femoral shaft nonunion after IM nailing, the success rate of the index surgery was significantly higher in the dynamic group than in the static group (100% vs. 75%, $p = 0.011$). A quarter of patients in the static group needed later dynamization to get bony union

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11 Intramedullary Nailing in the Deformed Medullary Canal

11.1 Autosomal Dominant Type II (AD II) Osteopetrosis

Autosomal dominant type II (AD II) osteopetrosis is a rare inheritable metabolic bone disease caused by a mutation in chloride channel 7 genes and osteoclast dysfunction [1]. It is characterized by hard but brittle bone, a narrow medullary canal, and a subtrochanteric fracture. Owing to the biomechanical superiority of IM nailing in subtrochanteric fracture fixation, it is an attractive option. In ordinary IM nailing, the ball-tip guidewire passes through the open medullary canal without difficulties, facilitating the reduction and reaming processes. Although IM nailing is the treatment of choice for subtrochanteric fractures, medullary canal deformities with obstruction and osteopetrotic bone hardness preclude ordinary IM nailing. In the existing case reports in the literature, IM nailing was rarely performed and led to unsatisfactory results due to insufficient reaming of the medullary canal [2–6]. In AD II osteopetrosis, the long bones are usually straight but have only traceable amounts of the medullary canal. Despite the narrow medullary canal, closed IM nailing is possible with the sequential use of instruments that could keep the reamers at the center of the partially obliterated medullary canal.

Case Illustration and Technique [7]
A 26-year-old man diagnosed with AD II osteopetrosis at the age of 10 sustained a displaced subtrochanteric fracture without comminution after a fall. Radiography of the pelvis and bilateral femurs revealed generalized osteosclerosis with "bone-within-bone" structures and narrow medullary canals. As the intramedullary canal was traceable on plain radiography and computed tomography, we planned an IM nailing (Fig. 11.1).

Fig. 11.1 Typical radiography and computed tomography findings of the pelvis and femur in a case of autosomal type II osteopetrosis. Generalized osteosclerosis with "bone-within-bone" structures are shown. Inlets, axial computed tomography images, are matched at the level of the femur [7]

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The patient was positioned on the fracture table under general anesthesia. The proximal fragment was derotated internally using long curved hemostatic forceps to obtain a good anteroposterior hip image [8]. A longitudinal skin incision was made from the palpable tip of the greater trochanter and extended proximally for approximately 5 cm. The entry point was prepared just medial to the tip of the greater trochanter. After placement of the 3.2 mm threaded guide pin on the starting point, the entry point was double-checked in the anteroposterior and axial views (Fig. 11.2). This 3.2 mm guide pin could enter only a few centimeters because of the bone hardness in the trochanteric area. An 8 mm starting reamer was used to enlarge the entry site for a few centimeters along with the guide pin. We then used a 4.9 mm drill bit to open the remnant medullary canal in the proximal fragment. A 4.9 mm drill bit was replaced with a 3.2 mm guide pin. The proximal fragment was reamed with a 14.5 mm tapered (trochanteric) reamer to accommodate a 13 mm nail body. We continued to ream the distal fragment with a 4.9 mm drill bit that followed the remnant intramedullary canal. Breakage of the drill bit makes IM nailing impossible, so it must be advanced with special care and kept in the center of the canal. After enlarging the remnant medullary canal, a ball-tip guidewire could pass the canal. Reaming was started at 7 mm and finished at 11.5 mm in 0.5 mm increments. The reamer must advance slowly in maximum revolutions per minute with frequent saline irrigation. This procedure was repeated every 2 cm until the reamer reached the distal one-third of the medullary canal. Overreaming of 1.5–2 mm is necessary to advance the nail manually. Forceful impaction on the nail with a hammer may break the brittle bone; thus, it is not recommended. After nail insertion, proximal interlocking screws were inserted through the targeting guide without difficulty. However, the insertion of a distal interlocking screw was quite difficult by freehand technique owing to the hardness of the osteopetrotic bone, which caused skidding of the drill bit. The postoperative radiograms showed that we made a mistake and left a gap in the fracture site. It was caused by contact between the transitional part of the nail and the distal fragment (the arrow in Fig. 11.3a). The proximal part of the distal fragment was not reamed enough to accept the thickened portion (shaft-body transitional part) of the nail. As delayed union was evident 6 months postoperatively, a dynamization procedure was performed (Fig. 11.3b, c). We exposed the proximal end of the nail, assembled a targeting guide, and removed the proximal and distal interlocking screws except for the one in the distal oval hole. The nail-targeting guide complex was pulled back until the fracture gap was closed. This movement also moved the distal locking screw to the dynamic locking mode (the screw moved to the distal end of the oval hole). We then reinserted the proximal interlocking screws. Callus started to form 3 months after the dynam-

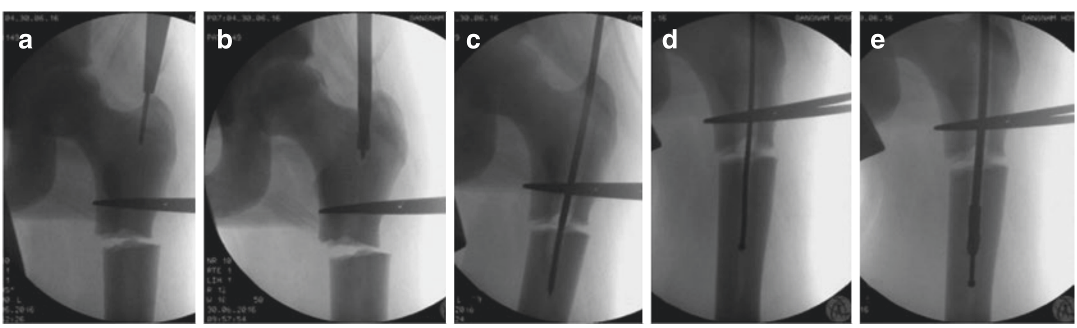

Fig. 11.2 Sequential processes of medullary canal reaming. (**a**). After placing the 3.2 mm threaded guide pin on the starting point, the entry point was double-checked in AP and lateral views. (**b**) An 8 mm starting reamer was used to enlarge the entry site for a few centimeters along with the guide pin. (**c**) A 4.9 mm-long drill bit was used to enlarge the remnant intramedullary canal. (**d**). After enlarging the remnant medullary canal, a ball-tip guidewire could pass the canal. (**e**). Reaming was started from 7 mm and completed at 11.5 mm in 0.5 mm increments [7]

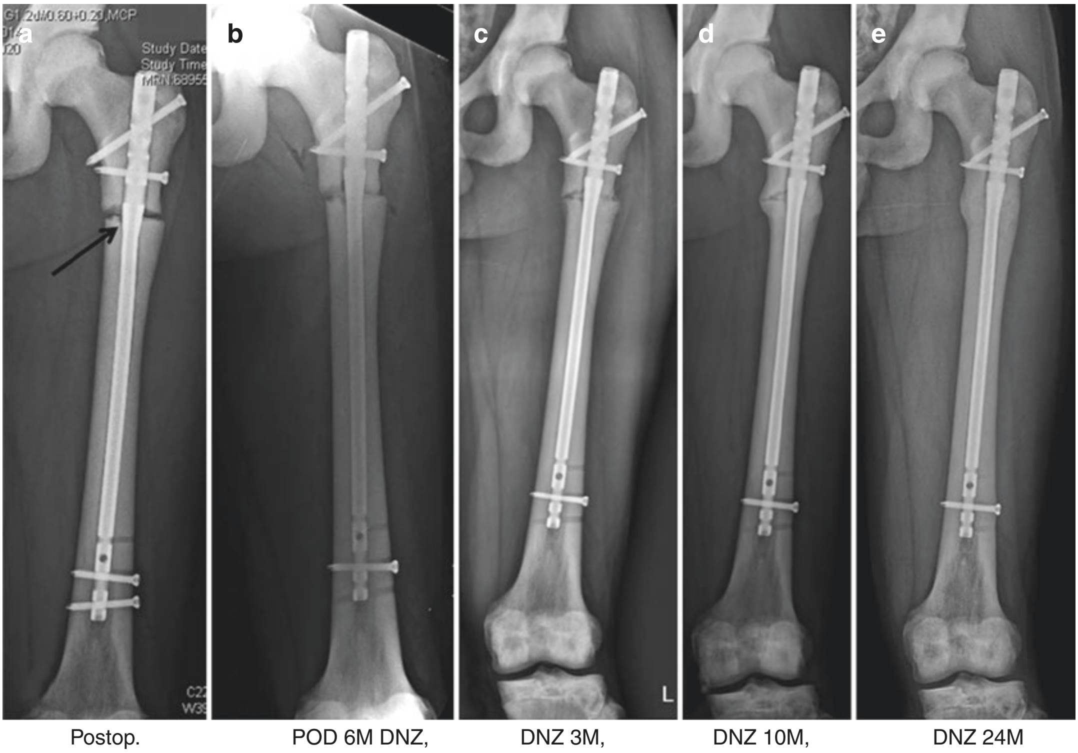

Fig. 11.3 Subtrochanteric fracture in a 26-year-old man with autosomal dominant type II osteopetrosis. (**a**, **b**) A subtrochanteric fracture was treated with intramedullary nailing. However, a gap in the fracture site occurred because of contact between the transitional part of the nail and the distal fragment (arrow). (**c**) Delayed union was evident 6 months after the operation, and dynamization (DNZ) was performed. (**d**) Callus formation was observed 3 months after the DNZ. (**e**). The fracture attained union 10 months after the DNZ. (**e**) The final radiograph 24 months after the DNZ shows complete union and remodeling of the callus. POD stands for postoperative day [7]

ization. Bony union was achieved 10 months after the dynamization (16 months after the injury) and remodeling was completed 30 months after the injury (Fig. 11.3d, e).

11.2 Obstruction of the Medullary Canal Due to Osteoblastic Bone Metastasis

Metastasis to the bone is common in lung, kidney, breast, and prostate cancers. However, prostate cancer is unique in that bone is often the only clinically detectable site of metastasis, and the resulting tumors tend to be osteoblastic (bone-forming) rather than osteolytic (bone-lysing). Bone metastases with an osteoblastic phenotype are the result of stimulation of osteoblasts or inhibition of osteoclasts (or both) by the cancer cells [9]. Osteoblastic bone metastasis sometimes obliterates the medullary canal that interferes with the passage of the guidewire, medullary reamer, nail, and interlocking screws (Fig. 11.4). The technique introduced in the previous section is also helpful in this situation [4, 7]. Namely, the sequential trochanteric reaming using a drill bit and lag screw reamer over the guide pin is necessary before trochanteric reaming. Once the trochanter is prepared to accommodate the nail body, the reduction finger is introduced into the proximal medullary canal for fracture reduction. After a femoral nail insertion, the proximal interlocking is again interfered with due to the hard bone around the femoral neck and trochanter. The drill tip must be frequently cleared to avoid heat necrosis.

Fig. 11.4 A 73-year-old male patient sustained a proximal femur fracture after a fall. The fracture happened just inferior to the osteoblastic metastasis from prostate cancer. The introduction of the guide pin into the entry site was difficult due to hard metastatic bone around the trochanter. At first, an 11 mm lag screw reamer was used to make a hole to facilitate the insertion of the 14.5 tapered trochanteric reamer. The proximal interlocking with 6 mm screw was difficult due to insufficient drilling of the hard bone by a 4.9 mm drill bit

11.3 Deformity of the Medullary Canal Due to Malunion of the Femoral Shaft

IM nailing has been a treatment of choice for segmental femoral fracture. Firm fixation at the proximal and distal segments with IM nail and interlocking screws makes it possible to start early range of motion exercise of the adjacent joints, full weight-bearing, and other rehabilitation. In malunion after transverse fracture of the femoral shaft, a simple osteotomy at the apex by using an open technique or intramedullary saw is a good option for correcting deformity because the nail templates the longitudinal axial alignment (Fig. 11.5) [10]. Of course, the length and rotational alignment must be checked to avoid unplanned operations. In malunion after segmental fractures or long oblique fractures, the deformed area is longer than in the malunion after a transverse fracture. Therefore, a long oblique osteotomy or double osteotomy is neces-

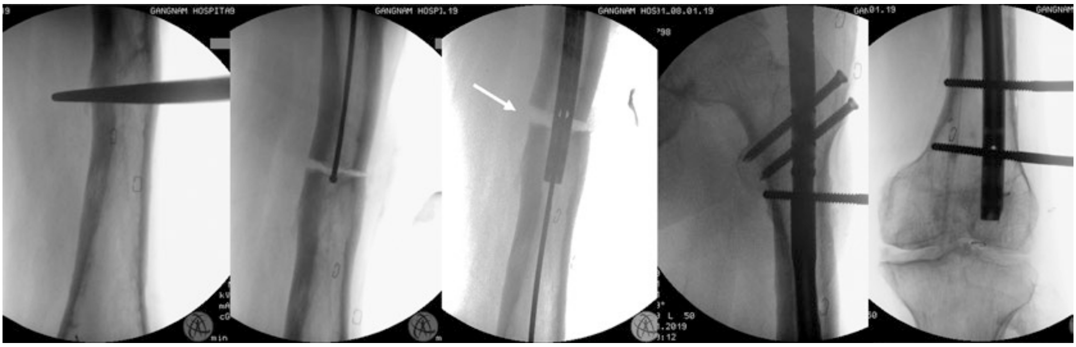

Fig. 11.5 A 70-year-old male patient had broken his femur during childhood and lived without specific symptoms except for the leg length discrepancy of 2 cm. He visited the clinic due to left knee joint pain, which developed recently. He needed a total knee replacement to control the knee pain, but the varus bowing at the femoral shaft and shortening had to be corrected before total knee replacement. We planned a simple osteotomy at the curve apex and IM nailing with a monorail type external fixator for postoperative lengthening. A white arrow indicates the opening of the medial osteotomy site, which implicates correction of varus deformity. The nail was used as a template for longitudinal alignment. The long transverse screws are the pins of an external fixator

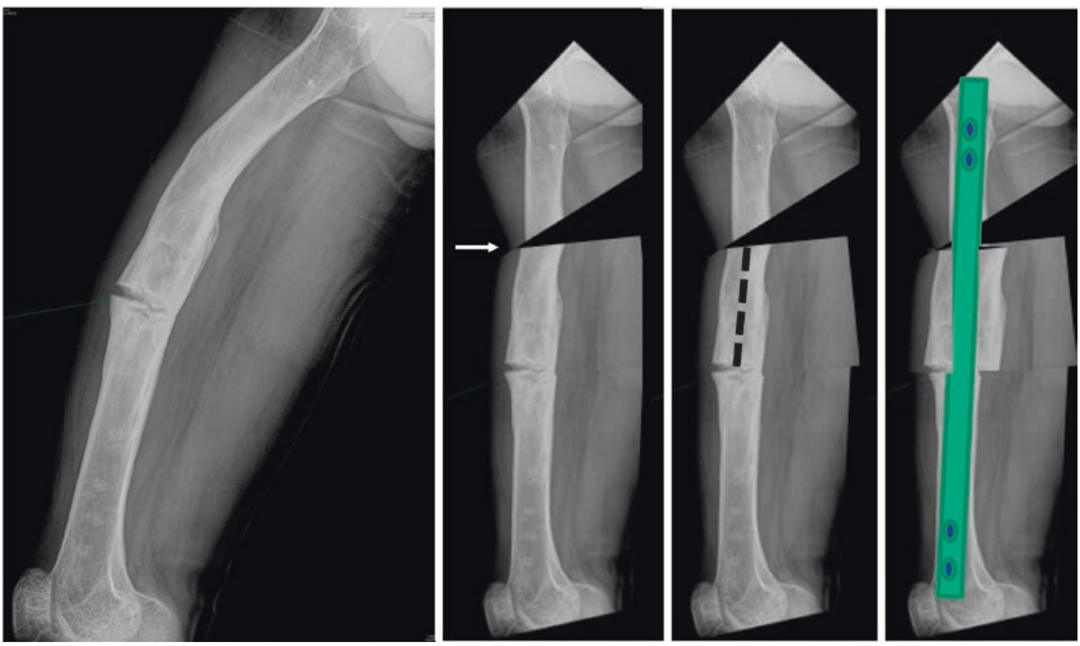

Fig. 11.6 Simulation of the so-called "clamshell osteotomy" technique. The malunited segment is transected perpendicular to the normal diaphysis proximally (white arrow) and distally (fracture in this simulation). Next, the transected segment is again osteotomized along its long axis (dotted black line in the middle segment) and is wedged open in a similar way to opening a clamshell. The proximal and distal segments of the diaphysis are then aligned using an intramedullary rod as an anatomic axis template and the contralateral extremity as a length and rotation template [11]

sary to correct this complicated deformity. Recently, Russell et al. reported the "clamshell osteotomy" technique for treating malunion in the femoral and tibial shaft. It simplified the operation and avoided complicated preoperative planning and precise osteotomy (Fig. 11.6) [11].

11.4 Hypophosphatemic Rickets

Familial hypophosphatemic rickets is defined as a group of disorders resulting from a defect in renal phosphate transport, which leads to phosphate wasting and hypophosphatemia. Familial hypophosphatemic rickets (FHR) is also characterized by abnormal regulation of vitamin D metabolism, resulting in normal 1,25-dihydroxyvitamin D concentrations despite hypophosphatemia [12]. The most common form of FHR is X-linked hypophosphatemic rickets. Mutations including nonsense mutations, missense mutations, splicing-site mutations, insertions, and deletions in phosphate regulating genes on the X-chromosome (PHEX) are known to be responsible for X-linked hypophosphatemic rickets. The PHEX gene consists of 22 exons that translate into a 749 amino acid protein. The PHEX gene encodes an endopeptidase that is involved in phosphate regulation. We treated a female patient with sporadic hypophosphatemic rickets harboring a novel deletion mutation (c.1586_1586 + 1delAG; p.Glu529GlyfsX41) at exon 14 and intron 14 junction, which caused a premature termination at codon 569 and possibly produced a truncated PHEX protein [13]. A 33-year-old female of very short stature (140 cm, 45 kg) was admitted to the emergency room complaining of leg pain. Physical examination revealed dental defects and deformities in the lower extremities, including bowing of the legs (Fig. 11.7). At the age of 2, she was diagnosed with rickets and started taking medications. Her height at the age of 17 was 125.6 cm. She had already undergone several surgical operations, including corticotomy and lengthening of shortened and bowed femur [15, 16]. Inorganic phosphate level was low [1.5 mg/dl (normal range 2.1–5.6 mg/dl)].

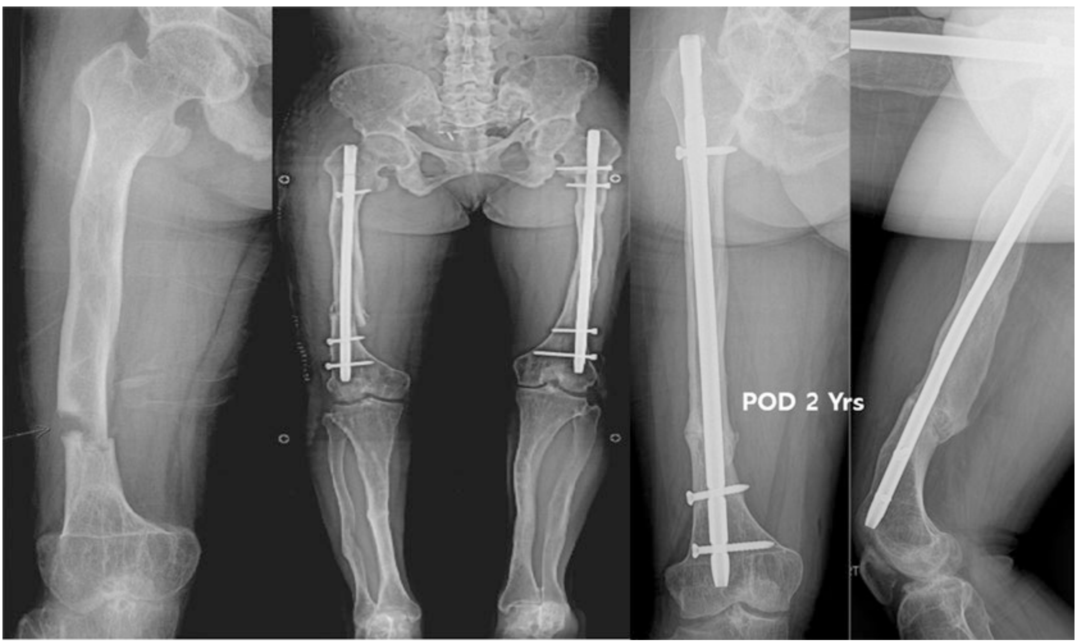

Fig. 11.7 The radiography showed a wavy shaft with a varus bowing deformity on both femora. The fracture occurred at the distal one-third of the right femoral shaft. The reduction was complicated due to varus bowing and the deformities of the femoral condyles, so open reduction was performed. The fracture took 2 years to be healed due to the deficits in the bone metabolism. Prophylactic nailing was performed on the left femur. External rotation IM nailing technique might be indicated in this case [13, 14]

11.5 Osteogenesis Imperfecta

Osteogenesis imperfecta, often referred to as "brittle-bone disease," is a heritable disorder characterized in most affected persons by either a reduction in the production of normal type I collagen or the synthesis of abnormal collagen as a result of mutations in the type I collagen genes. In type III osteogenesis imperfecta, a high frequency of fractures causes severe deformities and short stature, whereas in type IV deformities and dwarfism are present but are less severe. In most children with type III and many with type IV osteogenesis imperfecta, the disorder is progressive, with increasing deformity of the limbs and spine, dependence on others for help in walking, and chronic pain [17, 18]. For independent life, the maintenance of walking ability is crucial. Multiple histories of fractures in the lower limbs result in complex deformities, making the patient unable to walk unless the deformities are corrected and reinforced with some kind of support (Fig. 11.8). Cyclic bisphosphonate therapy reduces the risk of fractures, but correcting pre-

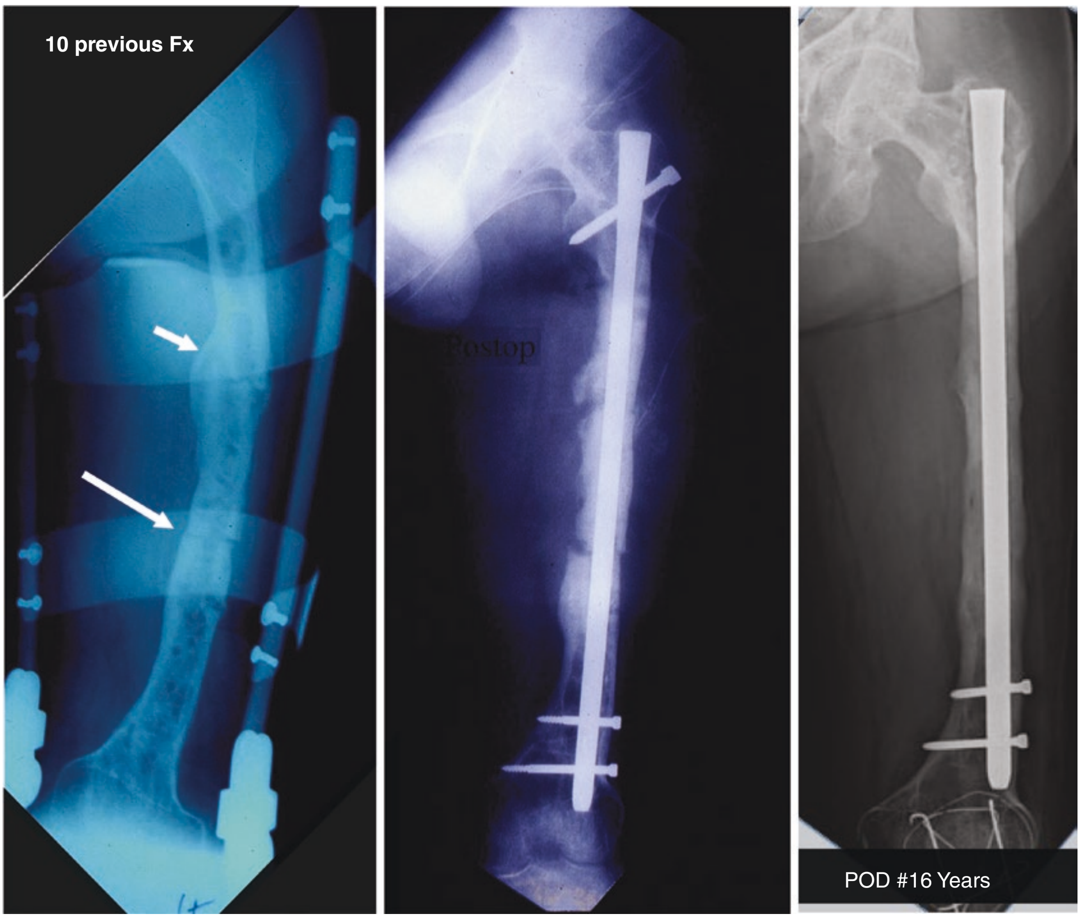

Fig. 11.8 This 30-year-old male patient who had suffered from 10 previous femur fractures experienced another new fracture at the mid-shaft of the bowed femur after a fall (long white arrow). One of the previous fractures resulted in malunion (short white arrow). IM nailing could be the only solution in the treatment of osteogenesis imperfecta in this adult patient. After osteotomy at the malunion site, IM nailing was performed to straighten the femur. Medial gaps on the osteotomy (short white arrow) and fracture site (long white arrow) implicate straightening of the bowed femur. The fracture healed uneventfully, but the proximal interlocking screw was removed due to pain 2 years postoperatively. He could walk without a brace until the last follow-up at 16 years postoperatively

existing deformity is required to improve walking ability [18]. Sofield or modified Sofield operation is often performed on children but not on adults [19–21].

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12 Limb Lengthening Using Intramedullary Lengthening Nail

Dong-hoon Lee

Orthopedic trauma surgeons encounter a variety of complex problems, which can have undesirable consequences regarding bone length and shape. That is, complex deformities such as angular deformities (varus/valgus, procurvatum/recurvatum), rotational deformities (internal/external torsion), and translational deformities (medial/lateral/anterior/posterior translation) may occur, including shortening of bone. These problems have traditionally been successfully reconstructed using an external fixator, but distraction osteogenesis or gradual correction using an external fixator causes considerable complications due to the long-term installation of the external fixator [1, 2]. The most common complications related to external fixators are pin-related problems. A pin-site infection was reported in 2–80% of cases, and a major infection was reported in up to 23% [1, 2]. In addition, severe pain, joint contracture, ugly scar, and psychological stress remain important issues [1, 2]. In order to reduce the duration of external fixation devices, hybrid-type surgeries such as LON (Lengthening Over Nail) [3–10], LOP (Lengthening Over Plate) [11–13], and LATN (Lengthening And Then Nailing) [14] have been developed. Although they have been widely used as surgical methods to date, it was not possible to completely overcome the problems caused by external fixation because they also required an external fixation device for a distraction period (see Figs. 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 7.10, 7.11, 7.12, and 7.13, Chap. 7, Bone defect due to open fracture and/or infection after osteosynthesis). In addition, since external fixation and internal fixation devices coexist, there is also a risk that minor pin-site infection may progress to deep infection [3, 4, 9].

Distraction osteogenesis using pure internal fixation without an external fixation device has been developed since the 1950s with the expectation that it can reduce complications such as infection, joint contracture, pain, and ugly scars caused by pins and also relieve the patient's mental burden. Clinical results are known for Albizzia®(Medinov-AMP, Roanne, France) [15–18], Fitbone®(Wittenstein, Igersheim, Germany) [19–22], ISKD®(Orthofix, Lewisville, TX, USA) [23–27], and PRECICE®(Nuvasive, San Diego, CA, USA) [28–36]. Among them, PRECICE nail is widely used with the most stable results. Even with the author's more than 300 PRECICE (version 2.3) nail experiences, the length target of distraction was obtained at 100%, and the accuracy in control of distraction was more than 99% (unpublished data). PRECICE 2.3 shows satisfactory mechanical and biological stability, but it has a limitation in that it cannot sufficiently carry weight until it achieves bony consolidation. In order to compensate for this

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weakness, STRYDE®(Nuvasive, San Diego, CA, USA) was developed to enable full weight-bearing even in lengthening phase but is out of market due to corrosion issue [37–39].

The mechanical and biological stability of the implant is very important because lengthening nails, which are extended by internal power without an external fixation device, may require revision surgery (exchange nail) if serious problems occur with the implant itself. Also, it is different from lengthening using an external fixator in that there is no way to cope with the occurrence of additional deformity due to muscle resistance during distraction.

Intramedullary nail has the advantage of dramatically reducing complications because there is no external pin that penetrates the skin and soft tissue. Appropriate preoperative planning and surgical technique can correct not only the length of bone but also diaphyseal or metaphyseal deformities at the same time. In addition, bone transportation for bony defects was also made possible without an external fixator either by bone transport intramedullary nail or by plate-assisted bone segment transport using lengthening nail [40].

12.1 Osteotomy (Lengthening) Site: Previous Fracture (Figs. 12.1 and 12.2) Vs. Intact (Figs. 12.3, 12.4, 12.5, 12.6 and 12.7)

Osteotomy and lengthening at the previous fracture site are attractive methods because they can correct the deformity at the same time if exists. However, soft tissue damage in the previous fracture site usually hinders bone regeneration, so it is preferable to make osteotomy at the uninjured diaphysis or metaphysis in the same bone if possible. Osteotomy is usually performed with a Gigli saw or an intramedullary saw.

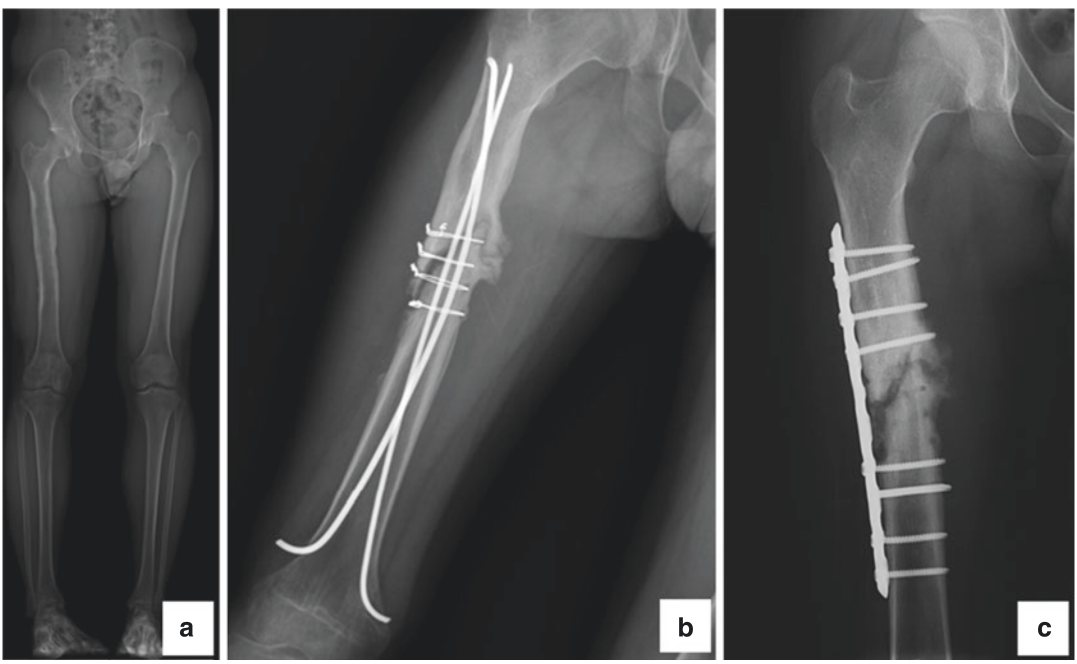

Fig. 12.1 Initial and past radiograms. A 19-year-old male patient showed 3 cm shortening of the right femur (**a**). The patient had a fracture of the right femur while riding inline skates 5 years ago and had to undergo two additional surgeries due to nonunion (**b**, **c**)

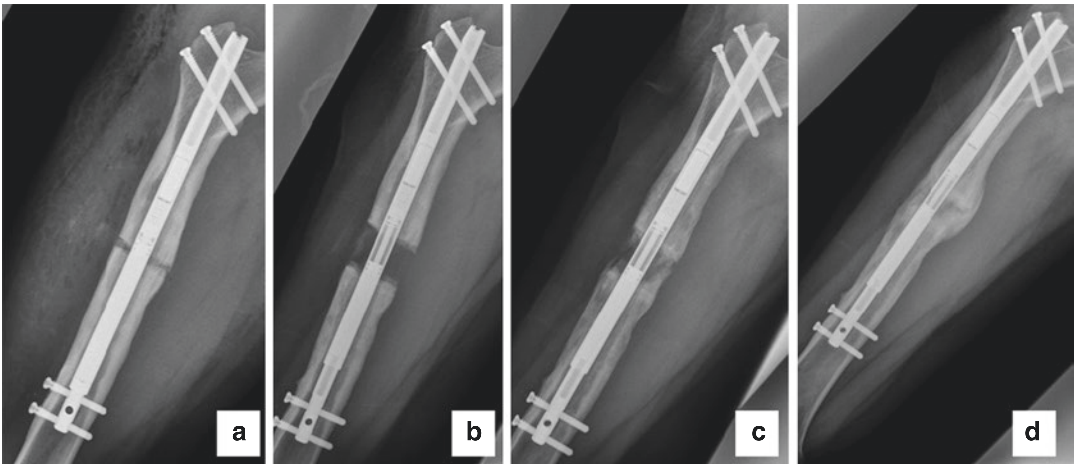

Fig. 12.2 Distraction (**a**, **b**) and consolidation phase (**c**, **d**) of the patient in Fig. 12.1 and consolidation phase. The selection of the osteotomy is very important, and it is best to avoid areas that are suspected of having previous soft tissue damages. But, in this case, osteotomy was performed in the area with a lot of periosteal damage, and it was observed that bone regeneration was significantly restricted during the distraction phase despite the slow distraction rate of 0.5 mm/day. Even in the consolidation phase, bone regeneration did not proceed well, so the union was completed with the help of Teriparatide (Recombinant PTH, Forsteo®)

Fig. 12.3 Initial and past radiograms. A 74-year-old male patient showed 5 cm shortening after an open, comminuted fracture of the left distal femur

Fig. 12.4 Osteotomy and lengthening of the patient shown in Fig. 12.3. Distal femur is the previous fracture site which has soft tissue damage, so bone regeneration is not expected to proceed well if osteotomy is performed here. In this patient, the retrograde nail was removed and osteotomy for lengthening was performed in the undamaged proximal area, and lengthening nail was inserted using an antegrade approach. In this case, ISKD® was used and "run away" occurred at a rate of 1.8 mm/day beyond the surgeon's control (the basic distraction rate for femoral lengthening is 1 mm/day). ISKD was withdrawn from the market due to this speed control problem [23]

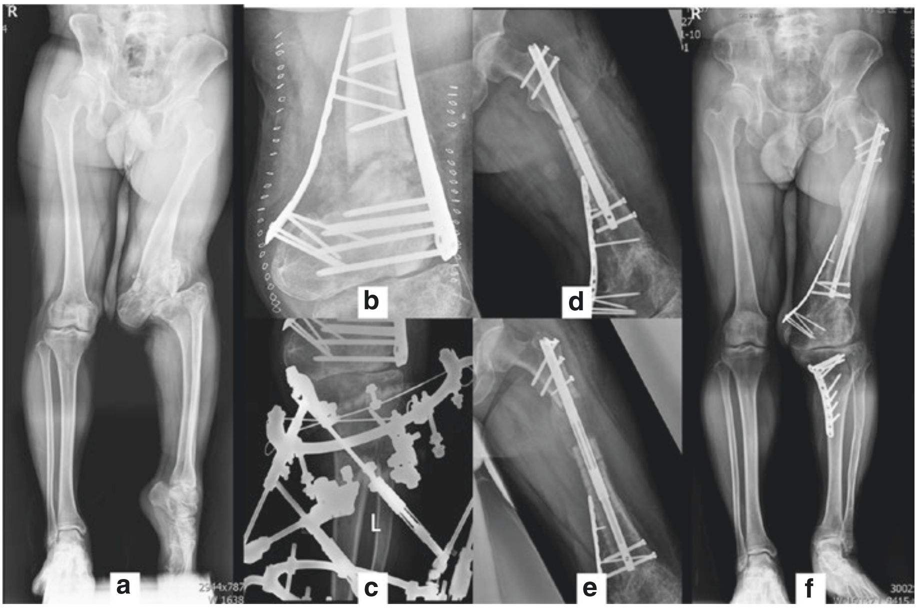

Fig. 12.5 Radiograms at the beginning and during the treatment. A 35-year-old male patient presented with leg length discrepancy and complex deformities of distal femur and proximal tibia (**a**). The patient said that he had undergone surgical treatment several times for a bone tumor that occurred in the left distal femur when he was young, and that bone deformation has progressed since then. Tibial deformity was corrected using an external fixator of the hexapod system (**c**). In the case of femur, there is a lot of soft tissue, so it is better to avoid external fixators as much as possible. In this case, the distal femur was corrected with acute correction and internal fixation (**b**), and then gradual lengthening was performed using PRECICE to complete the treatment (**d**–**f**)

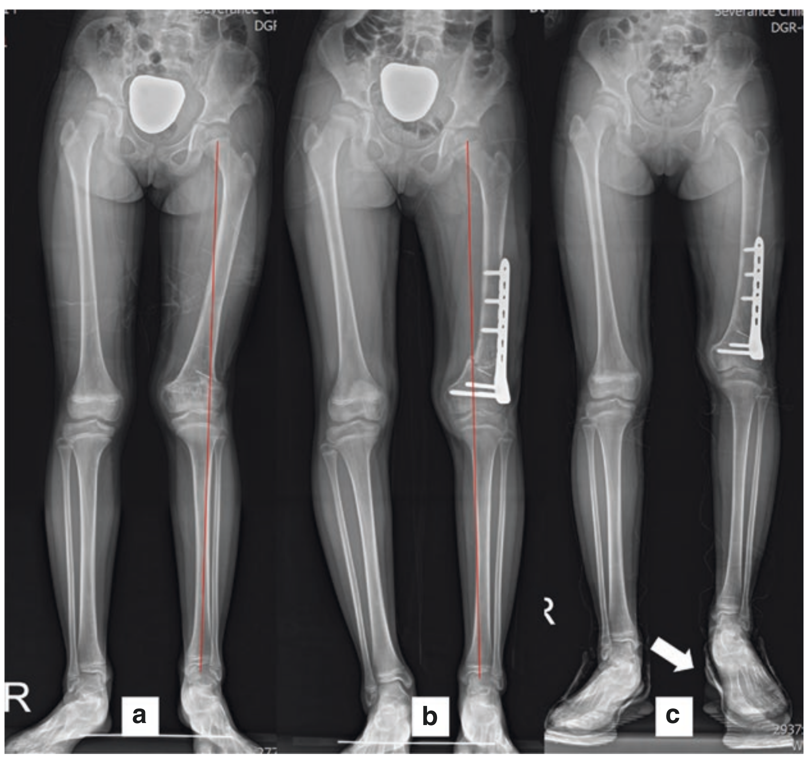

Fig. 12.6 Premature consolidation in adolescent patient. A 14-year-old female patient showed leg length discrepancy and distal femur valgus deformity (**a**). She suffered a trauma to her knee around the age of seven. An X-ray showed valgus deformity of the left distal femur (**a**). Since growth was not complete at the time of admission, we planned to correct the valgus deformity of the distal femur first (**b**) and fix the leg length discrepancy after growth was completed. While waiting for lengthening surgery, it is recommended to correct the leg length using a shoe lift (**c**) (arrow)

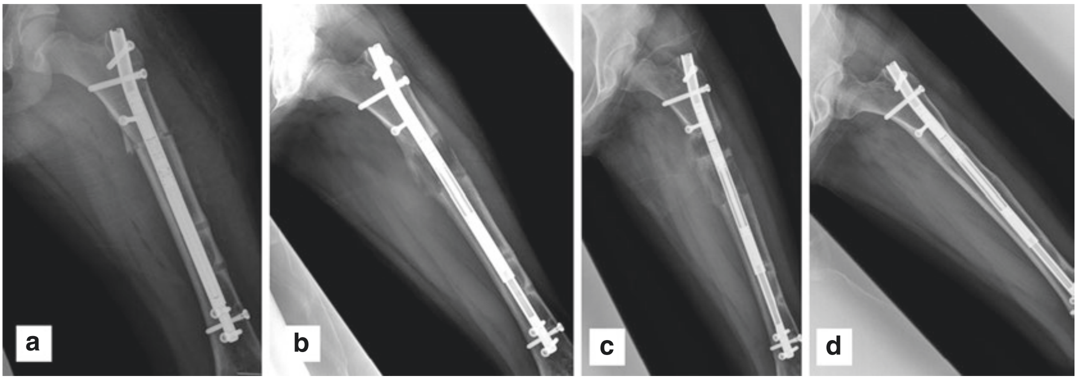

Fig. 12.7 Osteotomy, distraction, and consolidation of the patient shown in Fig. 12.6. The possibility of avascular necrosis of femoral head caused by vessel injury should be taken into account when determining the entry point for antegrade intramedullary nails in adolescent patients (**a**) (see Figs. 4.11 and 4.12, Chap. 4. Antegrade femoral nailing for femoral shaft fracture). In this case, the lateral entry was selected. During the distraction, premature consolidation occurred (**b**), so re-osteotomy was performed (**c**) and distraction was completed (**d**)

12.2 Osteotomy (Lengthening) Site: Diaphysis (Figs. 12.8, 12.9 and 12.10) or Metaphysis (Figs. 12.11 and 12.12)

IM nail provides a stable environment for distraction osteogenesis and weight-bearing when the osteotomy and lengthening are performed in the mid diaphysis. Two proximal and two distal interlocking screws are enough for stability. However, when the osteotomy is made at the distal metaphysis of the femur, medullary canal is too wide for stable fixation with an interlocking system alone. In such cases, Poller or blocking (interference) screws on both sides of the nail provide extra mechanical stability.

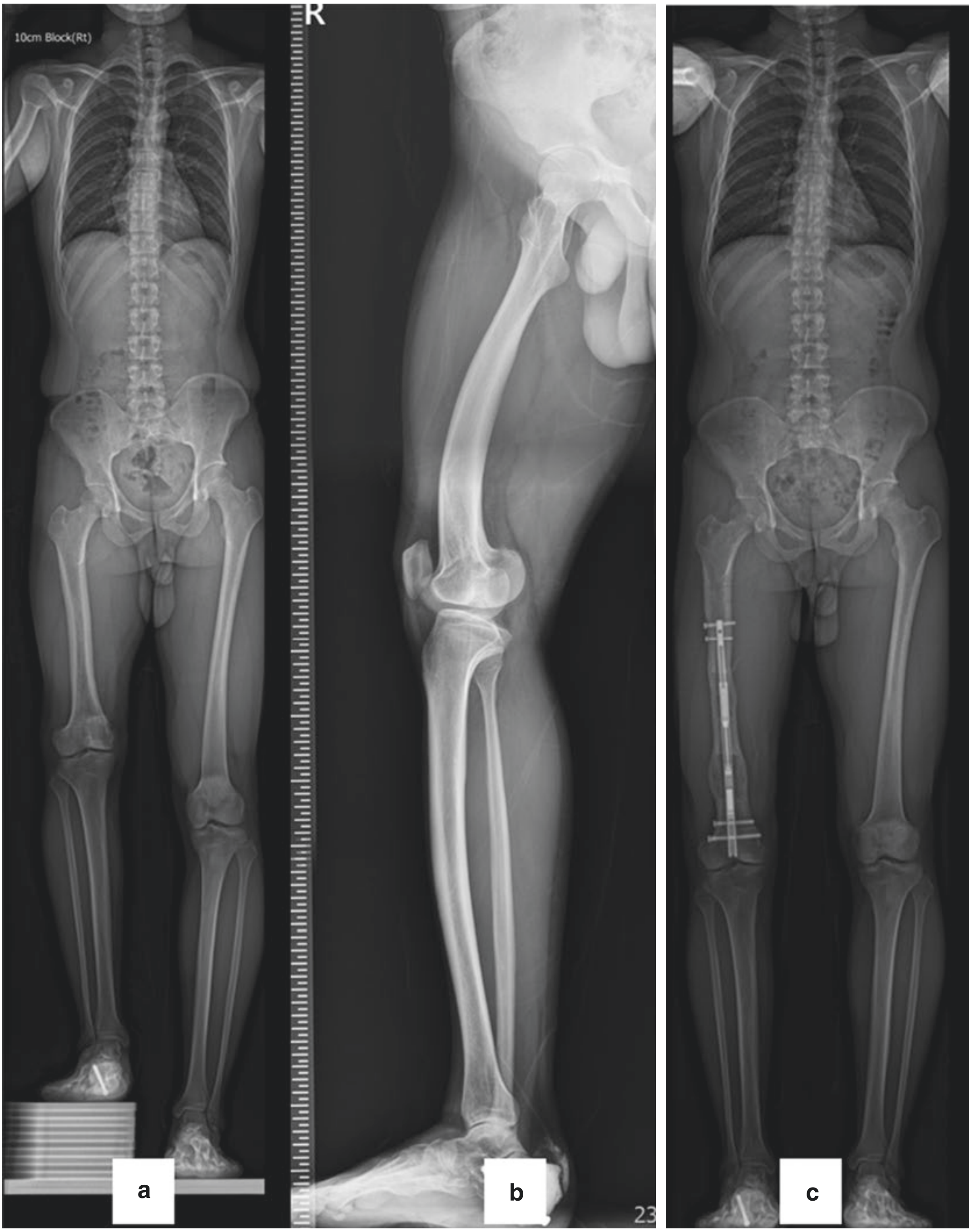

Fig. 12.8 Initial and final radiograms. A 26-year-old male patient suffered a fracture of the right femur at the age of 3 due to a traffic accident. At the time of admission, X-ray findings showed signs of damage to the growth plate of right distal femur, resulting in 12 cm leg length discrepancy (**a**) and flexion deformity of right distal femur (**b**). One of the important things in the treatment of leg length discrepancy is to check the functional leg length through a block test, not to determine the lengthening target just based on the radiography alone. In this case, functional discrepancy was confirmed to be 10 cm, and lengthening was divided into two stages and a total of 10 cm was lengthened (**c**)

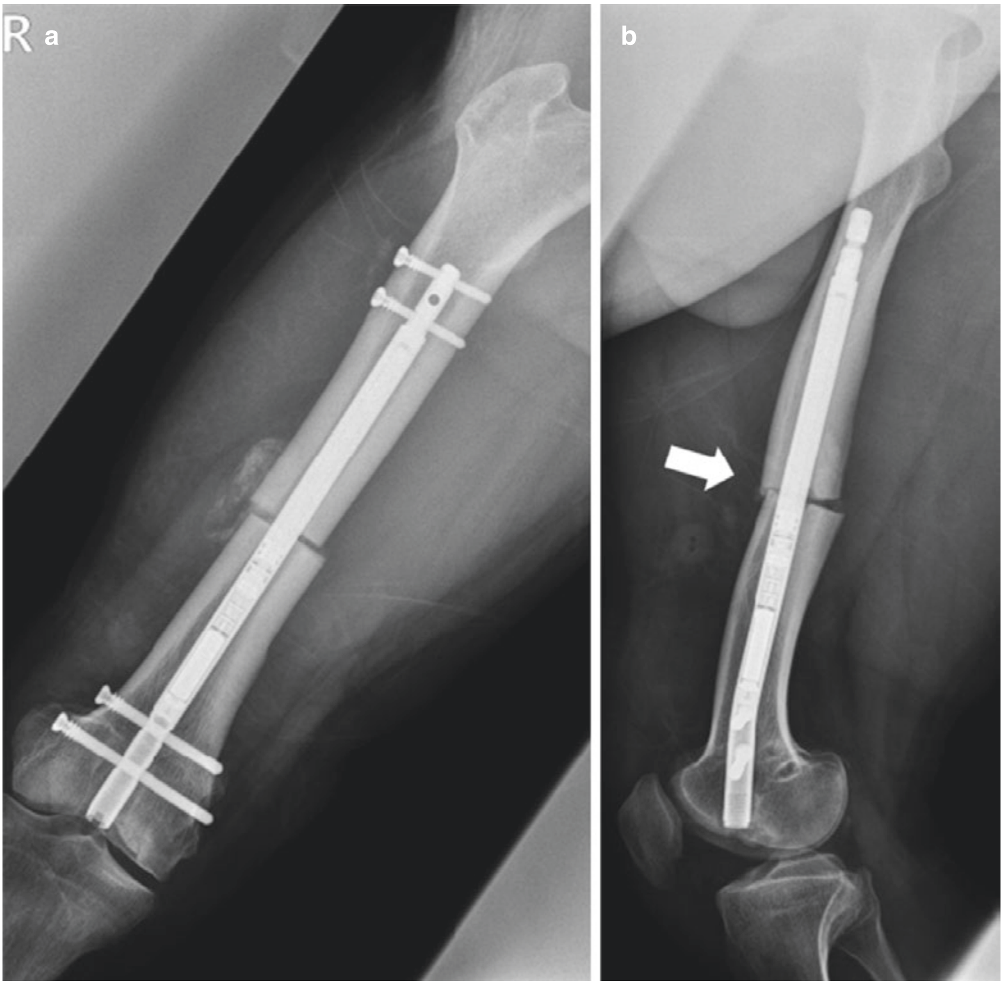

Fig. 12.9 Osteotomy. Level of osteotomy was determined considering simultaneous correction of flexion deformity of the femur (**a**, **b**) (arrow) and the secondary osteotomy level in the future

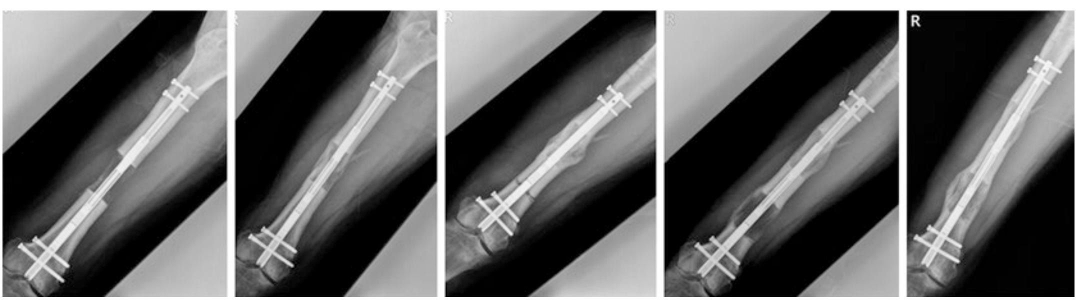

Fig. 12.10 Serial radiogram of staged lengthening of the patient shown in Fig. 12.9. As the first stage, the femur was lengthened by 5 cm. After confirming full consolidation of bone regeneration and full recovery of ROM of surrounding joints (hip, knee), an additional 5 cm was lengthened as the second stage (distraction rate: 1 mm/day)

Fig. 12.11 Initial and postoperative radiograms. A 43-year-old female patient showed a leg length discrepancy of 2.9 cm. According to her medical history, she suffered from osteomyelitis in her right femur as a child and complained of pain in her lower back, left knee, and pelvis. It was observed that sclerotic bone was formed in the medullary canal of the right femur. Since this interfered with reaming for intramedullary nails, osteotomy and lengthening were performed in the distal femur where a relatively long length of segment was secured

Fig. 12.12 Osteotomy, distraction, and consolidation of the patient shown in Fig. 12.11. As the distraction progresses, a large resistance is activated by the surrounding muscles, which can cause secondary bony deformities. When the osteotomy is performed in metaphysis, it is important to insert a blocking screw in consideration of muscle resistance during distraction

12.3 Summary

Osteotomy (Lengthening) Site: Apex of the Deformity or Intact Site

Minor deformity can be fixed with IM nailing after osteotomy at the apex of the deformity in the diaphysis. It applies to angular deformity (Fig. 11.5, Chap. 11) as well as to bowing deformity (Figs. 12.8, 12.9, and 12.10) of the diaphysis. Coexisting peri-articular deformity must be corrected before lengthening of the femur or tibia (Fig. 12.5).

Antegrade or Retrograde Nail

Antegrade type of lengthening nail is usually preferable, but obstruction or deformity of the proximal femur precludes its use. (Figs. 12.1, 12.2, 12.3, 12.4, and 12.5 vs. Fig. 12.11 and 12.12).

Rate and Rhythm of Lengthening

After osteotomy, spreading the gap typically four times a day, by one-quarter millimeter (¼ mm) every 6 h (a total of 1 mm a day), is recommended. When the distraction frequency (rhythm) is increased by autodistractor in the external fixator system, bone formation proceeds faster than routine procedure. Premature consolidation does occur in children and adolescents at the lengthening site, necessitating repeated osteotomy.

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13 Various Problems Encountered During the Removal of the IM Nail

The removal of the nail is necessary if pain persists at the buttock and thigh due to the prominence of a nail tip or a lag screw after the bone union. The removal of metalwork occasionally causes unexpected problems. Removal may not be possible and healed bone may be split during removal. In this chapter, I would like to describe the problems that you might encounter during nail removal. As for the removal of the broken hollow nail, see Chap. 9, Figs. 9.10, 9.11, and 9.12.

13.1 Failure of Attempted Removal of the Cephalomedullary Nail or Tibial Nail and its Solutions

Trochanteric and subtrochanteric fractures can occur in young patients after high-energy injury. Removal of the Gamma or long Gamma nail is usually requested by these young patients after consolidation when the prominence of the nail tip and lag screw or heterotopic bone over it causes discomfort in the buttock and proximal thigh. The failures in removing a Gamma nail and a long Gamma nail, which were used to fix subtrochanteric fractures, occurred in two young patients. The two male patients aged 18 and 25 sustained subtrochanteric fracture and underwent IM nailing using a Gamma nail. The removal of the Gamma nail was attempted after union due to thigh pain 1.5 and 3 years after the accident, respectively. The lag screw was exposed through a separate incision on the lateral aspect of the proximal thigh. A lag screw holder was attached and fixed to the tip of the lag screw. It was difficult to turn the holder by hand in any direction, and a vise grip was attached to the shaft of the lag screw holder to assist in the turning force. However, a forceful turning of the lag screw holder and a vise grip broke the lag screw holder. The removal of the lag screw and the nail body was abandoned (Fig. 13.1) [1]. To overcome this problem, we developed a device that resembles an extraction screw system (Fig. 13.2) [2]. Due to a mismatch between the longitudinal axis of the tibia and the nail, some difficulties have been reported, such as failure in the removal and iatrogenic fracture [3–6]. Once the extraction device fails to catch the threads at the nail end, removing the tightly fitted tibia nail in young patients after union is almost impossible. Thus, a surgeon must anticipate possible difficulties, and younger patients, in particular, should be warned thereof.

Removing a broken "InterTAN" cephalomedullary nail system is challenging due to the unique integrated interlocking lag screw system. It consists of a main lag screw above and a compression screw below. To remove the main lag screw, a compression screw must be disengaged.

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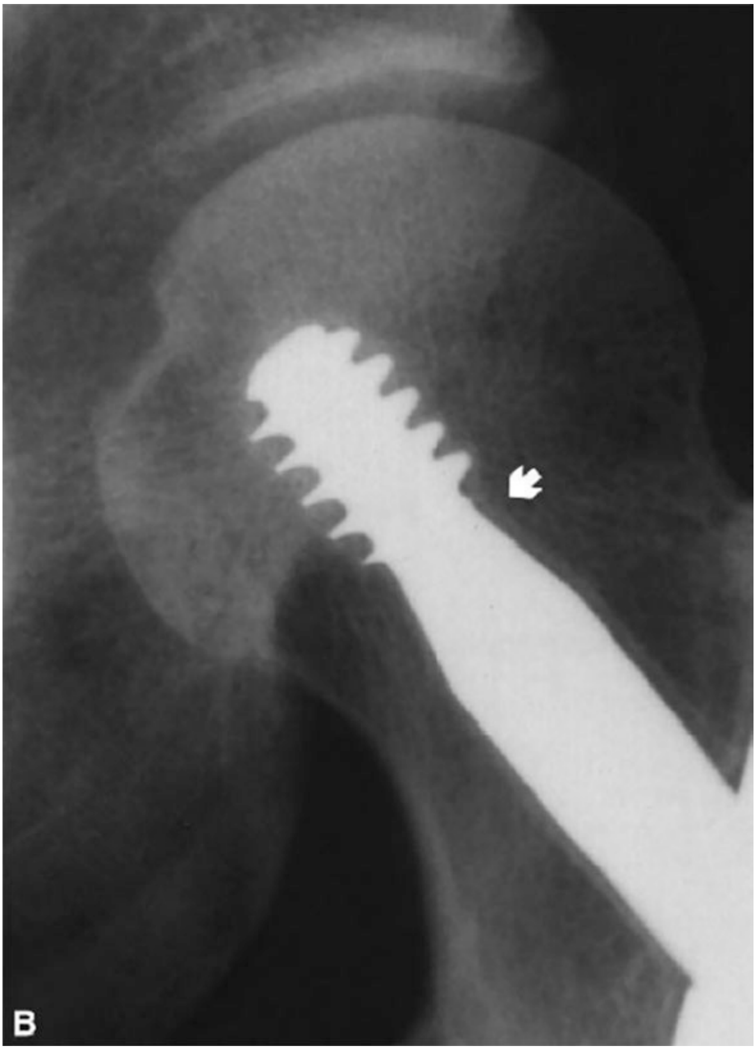

Fig. 13.1 An 18-year-old male patient sustained a subtrochanteric fracture, which was treated with a long Gamma nail. Attempted removal of the nail failed due to hard bone formation surrounding the lag screw 1.5 years after the accident. A close-up view of the lag screw confirmed new bone formation in the notch just beneath the screw thread (arrow). New bone formation around the screw threads is also noted

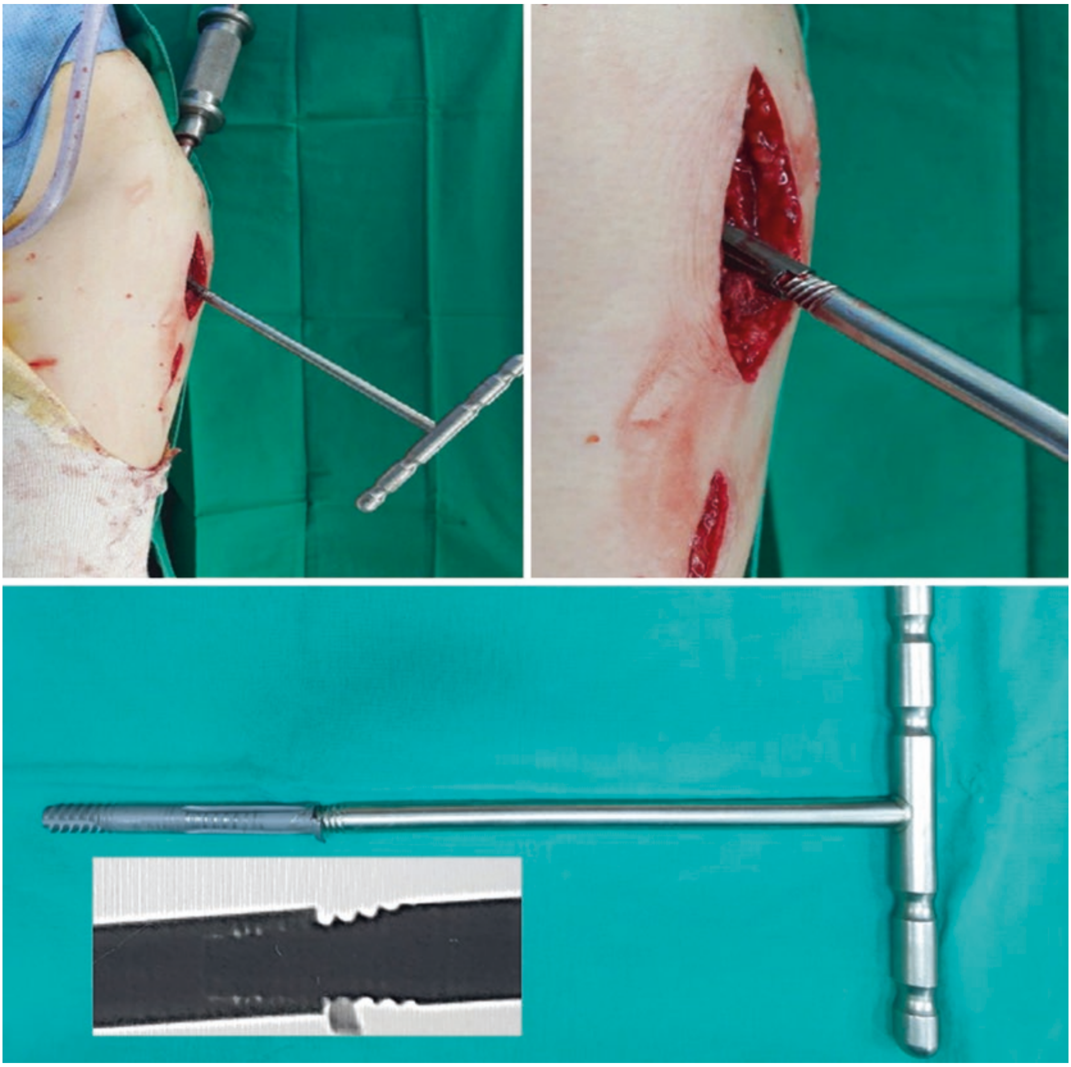

Fig. 13.2 The holding notches located at the distal end of the lag screw are weak in the cephalomedullary nail made of titanium. To solve this problem, we developed a device resembling a reverse-threaded corkscrew with a T-handle. When the regular lag screw holder can no longer grip the lag screw, we apply that device to the end of the lag screw. The tapered end advances into the lag screw, and an anticlockwise rotation turns and releases the jammed lag screw. Inlet is a fluoroscopic view of the reverse-threaded corkscrew and crushed end of the lag screw. The mechanism resembles the removal system for a rounded hexagonal locking screw head

Otherwise, it is impossible to turn the main lag screw. We were the first to report the removal technique of a broken "InterTAN" nail in the literature (2017) (Fig. 13.3) [7, 8].

For the removal of a long nail fragment, see Chap. 8, "Removal of a broken nail in association with nonunion of the subtrochanteric fracture." The removal of a small nail fragment is possible by the following method (Fig. 13.4). The nail can be stuck during its removal from the medullary canal. In that case, a lateral longitudinal osteotomy is necessary to open the cortex while removing the nail (Fig. 13.5). If the broken interlocking screw interferes with removing the nail, a Steinmann pin is a good tool to expel the broken screw from the bone (Fig. 13.6).

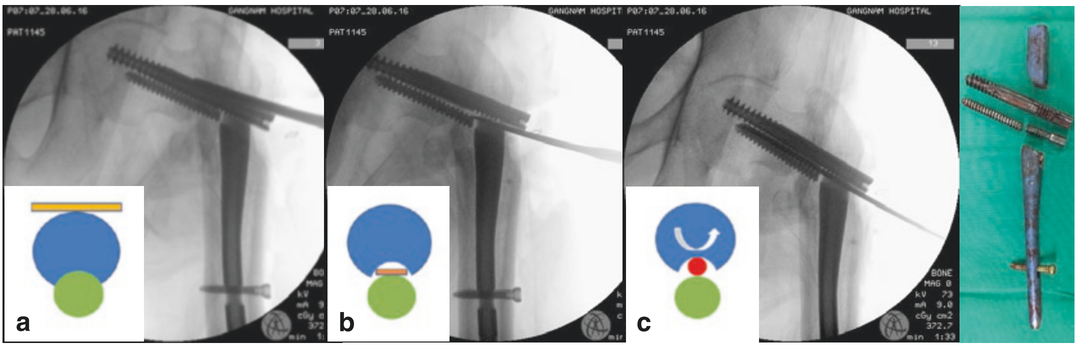

Fig. 13.3 The "InterTAN" cephalomedullary nail system involves a unique integrated interlocking lag screw system. It consists of a main lag screw above and a compression screw below. The screws are integrated by their threads and can be inserted sequentially through the lag screw hole in the nail body. In the fluoroscopic images, nonunion of the subtrochanteric fracture and associated varus deformity with metal failure at the lag screw hole is noted. The removal of the lag screw was essential for the removal of the nail and subsequent revision surgery. However, the broken compression screw in the femoral neck and head interfered with the main lag screw removal. Cross-sectional images of the integrated lag screw system are presented. The yellow, blue, green, and red symbols depict the osteotome, main lag screw, compression screw, and Steinmann pin. (**a**) A small space is made above the lag screw using an osteotome. (**b**) A small osteotome is used to disengage the integrated threads between the lag and compression screws. (**c**) A No. 2 Steinmann pin is inserted, and it fills the space through the groove located underneath the lag screw. Now, the lag screw can be turned and removed

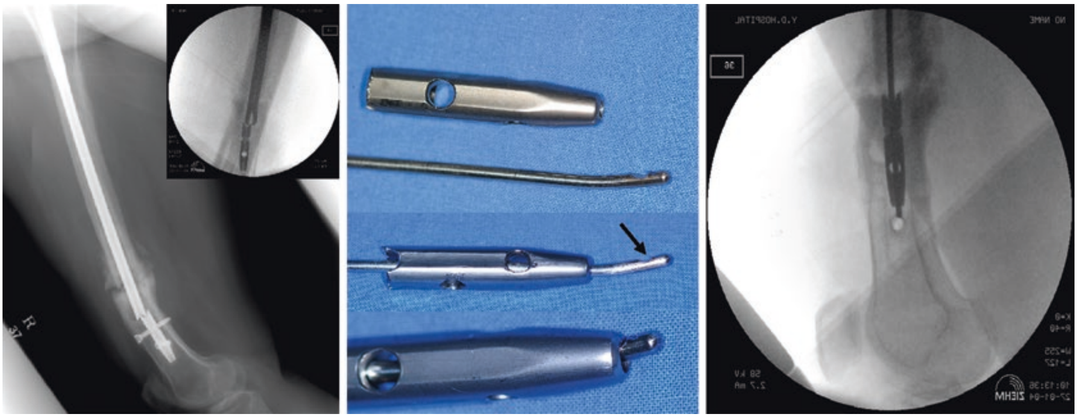

Fig. 13.4 The removal of a small nail fragment. It is difficult to remove the small distal nail fragment using pituitary forceps, a blocking wire technique, and a ball-tip/straight guidewires combination method. The passage of a ball-tip guidewire is sometimes challenging if the hallow is narrow. In such a case, bend a straight guidewire's tip and cut the notch (black arrow) on the concave side of the guidewire about 5 mm above the end. As a result, the bent straight guidewire can pass the narrow hollow, and the notch can hold the distal opening of the nail fragment (right image) [9]. The risk of slippage is high in the long distal nail fragment due to high resistance to removal. Therefore, this technique is usually applicable to a small nail fragment only

Fig. 13.5 A 30-year-old male patient was transferred to the emergency room due to a protruded femoral nail through the surgical wound. A surgeon attempted to remove the femoral nail which had been in the femur for 3 years after an accident. While removing the nail, the nail was jammed at the isthmus and could not be retreated or advanced; so he closed the surgical wound but could not cover the protruding nail tip. I tried to remove the nail by usual manners, but this did not work, either. In the end, I performed a longitudinal osteotomy at the lateral aspect of the proximal femur for 15 cm using an oscillating saw. Lateral osteotomy was opened like a clamshell while the nail moved toward the buttock. Cerclage wires were applied for safety. The osteotomy site healed uneventfully

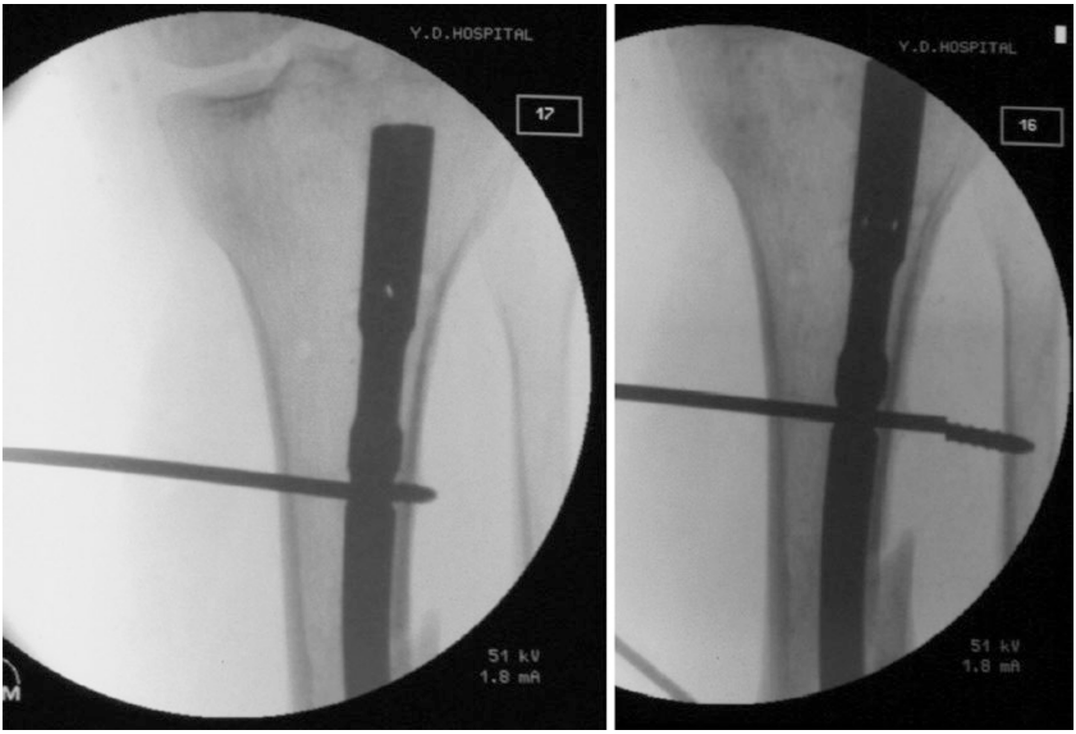

Fig. 13.6 The broken interlocking screw sometimes interferes with the removal of the nail. In that case, a Steinmann pin is cut perpendicularly to make a blunt end and is introduced into the interlocking hole where the broken distal screw tip is stuck. Tap the broken screw to expel from the bone. The broken tip can be retrieved using another incision

13.2 Fracture of Femur or Tibia during Removal of a Nail

Zickel nail [10]: While the Zickel nail is an excellent device for fixation of pathological subtrochanteric fractures in elderly patients, it is not recommended to be used in young patients who will most likely want the nail to be removed. Yelton and Low (1986) described four so-called iatrogenic subtrochanteric fractures that occurred as complications of removing the Zickel nail [11]. Subsequently, Ovadia et al. (1988) also reported similar fractures in 12 patients [12]. Therefore, the Zickel nail is no longer indicated in the high-energy subtrochanteric fractures in young patients.

Ace tibia nail: Takakuwa et al. (1997) reported posterior fractures of the tibia during removal of Ace Aim tibial nails. Local posterior fractures occurred in four of the 19 patients (21%). They experienced considerable difficulty in the removal of each of the nails, and the pattern of the fracture was very similar in all four of them. The fracture line was fissured, involving from one-quarter to one-third of the local circumference of the tibia, which was displaced posteriorly. The injury was in the middle third in two patients and in the lower third in two. The patients all complained of pain but were successfully managed by partial weight-bearing on crutches for 3–4 weeks [6]. Bridging callus appeared in all of them, and the healing proceeded satisfactorily. Difficulties in removing tibial nails after union have been reported in the Lottes and Alta tibial nails, too. The use of these nails in young patients requires caution [5].

13.3 Femoral Neck Fracture after Removal of Cephalomedullary Nail

The causes of femoral neck fracture after fixation and healing of the trochanteric and subtrochanteric fracture are not clear. Subcapital femoral neck fracture occurs around the margin of the lag screw of the sliding hip screw, fixed angle plate, and cephalomedullary nail. To prevent this complication, it is recommended that the lag screw is inserted close to the subchondral bone of the femoral head [13, 14]. Femoral neck fractures after removing the implants, which were inserted to treat trochanteric fracture, have also been reported (Fig. 13.7). They occur after removing the sliding hip screw, fixed angle blade plate, and the Gamma nail [15–17]. Kukla et al. studied the biomechanics of the femur after implant removal. Removal of the Gamma nail decreased the resistance to fracture of the femoral neck by about 41% compared to the 20% of dynamic hip screw. The lag screw diameters of the dynamic hip screw, Proximal Femoral Nail, and Gamma nail are 8 mm, 11 mm, and 12 mm, respectively. When the diameter of the lag screw reaches a certain size, the incidence of fracture increases geometrically. If excessive sliding of the lag screw causes persistent hip pain after intramedullary hip nailing, the lag screw should be replaced with a shorter one rather than removing the implant, because the bone defect after implant removal further weakens a femoral neck with preexisting osteoporosis [18]. In addition, pain in the hip region may imply an impending subcapital femoral neck fracture. Filling up the defect after hardware removal with bone graft or bone graft substitute may be considered if removal of the nail and lag screws is unavoidable.

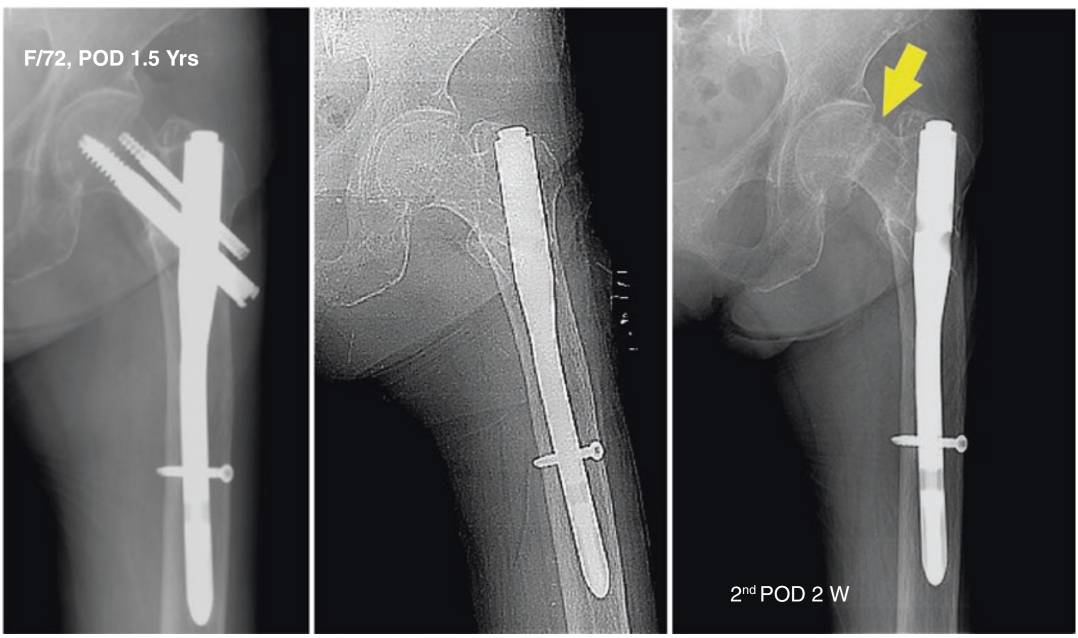

Fig. 13.7 Eighteen months follow-up radiograph after insertion of the Proximal Femoral Nail shows excessive sliding of the hip pin and femoral neck screw (left). Immediate postoperative radiograph of the hip after removal of the lag screws (middle). Postoperative radiograph at 2 weeks shows a subcapital femoral neck fracture (arrow on the right)

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